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THESIS

OPTIMIZATION OF THREE DIMENSIONAL COMBINED TRUSS/FRAME STRUCTURES

by

Gregory L. Bender

October 1982

Thesis Advisor: G.N. Vanderplaats

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The finite element code may be used for analysis only, or may be coupled to an optimizer of the user's choice. The

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displacement method is used for static analysis, and structure natural frequencies are calculated via the sub-space iteration method.

Flexibility is provided for expansion to other than tubular frame elements, and provisions are made for the future growth to panel and other types of structural elements.

Documentation is provided to facilitate use of the code. A User's manual is presented with examples and results. An explanation of how this code may be coupled to an optimizer is also provided.

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Optimization of Three Dimensional Combined Truss/Frame Structures

by

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Lieutenant, United States Navy
B.S.Nuc.Eng., North Carolina State University, 1974

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requirements for the degrees of

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AND

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The finite element code may be used for analysis only, or may be coupled to an optimizer of the user's choice. The displacement method is used for static analysis, and structure natural frequencies are calculated via the subspace iteration method.

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Documentation is provided to facilitate use of the code. A User's manual is presented with examples and results. An explanation of how this code may be coupled to an optimizer is also provided.

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I. INTRODUCTION

The task of the Engineer is to provide the best solution to the customer's problem. Usually the "best" solution is the one that does the job with an adequate margin of safety, is aesthetically pleasing, and is economically feasible. The solution may be reached through various means, but efficient use of design tools, as well as efficient use of materials is important since both add to the overall cost of the product. Design optimization is one method that can be used to maximize the efficiency of a structure by minimizing its weight and, presumably, cost.

Optimization of structures has had continuing changes since its development in the early 1960's with an active area of research being elastic structures. The main goal is to design structural systems that efficiently perform specified purposes. Since most physical structures can be modeled by the finite element method, a computer program can be written to perform the necessary calculations to solve the problem.

The purpose of this research was to develop a finite element code that could be used to analyze a combined truss/ frame structure and could be easily coupled to an optimizer; thus providing a useful tool for designing such structures

as, for example, ships' masts. This code expands the previous work by Fitzgerald [Ref. 1] on truss structures to the more general six degree-of-freedom truss/frame case.

The design problem considered in this study is the optimization of three-dimensional statically indeterminant combined truss-frame structures under varying load conditions and subject to a variety of constraints. The objective is to minimize the weight of the structure where the design variables are member sizes and joint coordinates. Constraints include: maximum normal stress; maximum joint displacements; minimum structure natural frequencies; Euler buckling; and in the case of the tubular frame elements, local or shell buckling.

In the present code, all gradient information is calculated by the finite difference method. Modification of the code to permit calculation of gradients analytically has been identified as a necessary future extension.

This document describes the use and capabilities of the finite element computer code to be coupled to an optimizer. The user's manual presented in Chapter V contains a simple design example in which the program is coupled to the CONMIN optimization code [Ref. 2]. Additionally, guidelines for coupling the code to an optimizer of the user's choice are presented.

Several examples demonstrating the program under a variety of conditions are presented. Conclusions and recommendations for future work are given.

II. ANALYSIS

A. INTRODUCTION

When the finite element method of analysis is used to design optimization, two objectives must be kept in mind. First, the number of analyses for the structure should be kept to a minimum. Second, the amount of gradient information required during the design process should be minimized to shorten run times and minimize computer storage requirements.

B. STATIC ANALYSIS

Initial formulation of the problem must include approximate member areas in the case of truss elements, and for frame elements, characteristic dimensions (for tubular members: mean diameter and wall thickness); material properties (which may be different for each member); a set or sets of external loads; any non-structural attached masses; and specified joint support conditions.

The analysis for the stresses and deflections at the joints must satisfy the conditions of equilibrium of forces at the nodes and geometric conditions of compatibility of deformation. In this analysis the structure is assumed to behave in a linearly elastic fashion. The weight of an individual member is not inherently included as part of the

specified load conditions; but, as an option, half of the weight of each member may be applied at the member's end-points as an additional load in the negative Y-direction.

For this analysis, the following assumptions are made: truss and frame members are treated as discrete entities; truss elements have three translational degrees of freedom at each node and are treated as pin-connected; frame elements have three translational and three rotational degrees of freedom at each node and are treated as fixed-fixed beams; and loads and reactions are applied at the joints as shown in Figure 2.1.

The Displacement (Stiffness) method for finite element analysis [Ref. 3] is utilized where

$$\underset{\approx}{K}\underset{\sim}{u} = \underset{\sim}{F} \qquad (3.1)$$

and where $\underset{\approx}{K}$ is the global stiffness matrix, $\underset{\sim}{F}$ is the vector or vectors of applied loads, and $\underset{\sim}{u}$ is the vector or vectors of displacements. The method used herein is an extension of that described by Felix and Vanderplaats [Ref. 4]. By applying the constitutive stress-displacement relationships, stresses in the elements may be recovered.

C. DYNAMIC ANALYSIS

When constraints on the system's natural frequencies are to be considered, the design process requires the solution of an eigenvalue problem. The sub-space iteration

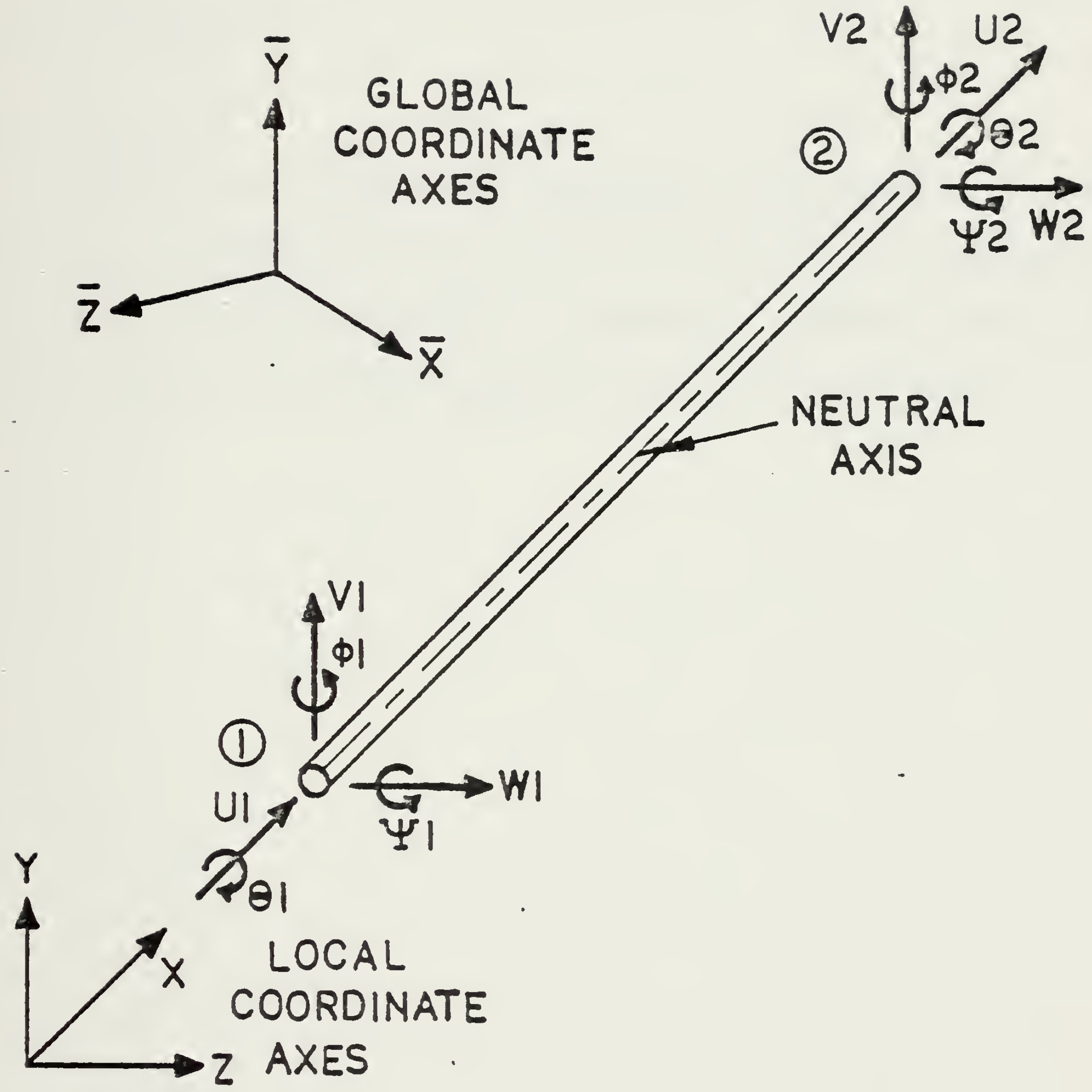

Figure 2.1 FORCE ORIENTATION CONVENTION FOR AN ELEMENT

method of Bathe and Wilson [Ref. 5] is used to solve for the desired number of lowest eigenvalues and the associated eigenvectors. This method is reasonably efficient for a small number of lowest frequencies for a large problem, and is well suited for re-analysis when small changes are made in the design.

D. GRADIENTS

Gradients are currently calculated with respect to member sizes and coordinates only by finite difference techniques. Inclusion of the capability to calculate gradients analytically is identified as a needed extension to this work.

III. OPTIMIZATION

A. INTRODUCTION

The primary objective of structural optimization is to design systems that efficiently perform specified purposes. Selection of a specific optimizing algorithm must take into account the following: 1) the structure should be analyzed as few times as possible; 2) the algorithm should minimize the amount of gradient information required; 3) the algorithm should provide reasonable assurance that an optimum or near-optimum design will be reached.

B. GENERAL FORMULATION

The general statement of inequality constrained minimization is as follows:

Minimize

$$F(\underset{\sim}{X}) \qquad (4.1)$$

Subject to:

$$G_j(\underset{\sim}{X}) \leq 0 \qquad j=1,m \qquad (4.2)$$

$$x_i^{\ell} \leq x_i \leq x_i^{u} \qquad i=1,n \qquad (4.3)$$

where $F(\underset{\sim}{X})$ is the objective function to be minimized. The functions $G_j(\underset{\sim}{X})$ are the set of inequality constraints to be met. The vector $\underset{\sim}{X}$ contains the design variables.

The inequality constraints, $G_j(\underset{\sim}{X}) \leq 0 \quad j=1,m$, must be satisfied for the design to be accepted as feasible. Side constraints, x_i^ℓ and x_i^u, are lower and upper bounds on the design variables. The objective function must be minimized as much as possible while still satisfying all inequality constraints. In the case that it is not possible to satisfy all constraints, the most nearly feasible solution must be found. Felix and Vanderplaats [Ref. 4] is an excellent source for the basic structural design formulation.

C. DESIGN VARIABLES

The vector $\underset{\sim}{X}$ contains the design variables; in this case, member characteristic dimensions for frame elements, cross-sectional areas for truss elements, and spacial coordinates of the joints. The user may elect to optimize the structure weight with respect to any combination of the above variables.

For truss elements, where normal stress is dependent only upon the magnitude of the cross-sectional area of an element and not the distribution of that area, it is sufficient to use the area as the design variable as long as the Euler buckling stress can be related to the cross-sectional area. For frame elements where stresses are dependent on area distribution, more flexibility is allowed by varying two characteristic dimensions and allowing the code to calculate the section properties from these.

In the case of tubular elements, the characteristic dimensions are mean diameter and wall thickness; from which area, bending and polar moments, and maximum radial dimensions are generated.

The optimum geometry problem requires that the joint coordinates be design variables. The x, y, and z coordinates of a joint are treated as separate design variables.

In many cases it is desirable to link a set of design variable together to preserve symmetry, limit the number of variables to be solved, or to limit the number of unique elements to be manufactured. The code has provisions for design variable linking by which two or more variables may be linked in equality or some fixed ratio.

D. OBJECTIVE FUNCTION

The objective function under consideration is weight

$$F(\underset{\sim}{X}) = \sum_{i=1}^{NE} \rho_i A_i L_i \qquad (4.4)$$

where ρ_i is the weight density (in consistent units) of the material of the ith element, A_i is the cross-section area of the ith element, and L_i is the length of the ith element and NE is the number of elements in the structure.

E. CONSTRAINTS

This code is designed to accommodate constraints on maximum normal stress, Euler buckling, local or shell buckling,

maximum joint displacements, and minimum natural frequencies of the structure. All constraint values are normalized.

1. Stress:

For truss elements, maximum normal stress σ_M is calculated directly from the element tensile forces. For frame elements; tensile stress σ_A, maximum bending and shear stresses σ_B and σ_T are calculated. Maximum and minimum normal stresses are

$$\sigma_{max} = \text{max magnitude of } \frac{\sigma_A \pm \sqrt{(\sigma_A{}^2 + 4\sigma_T{}^2)}}{2} \qquad (4.5)$$

$$\sigma_{min} = \text{min magnitude of } \frac{\sigma_A \pm \sqrt{(\sigma_A{}^2 + 4\sigma_T{}^2)}}{2} \qquad (4.6)$$

The upper and lower bounds on stress may be different for each member, but are taken to be the same for every loading condition.

2. Local or Thin Shell Buckling

The stress at which local or thin shell buckling occurs is given by:

$$\sigma_{L_i} = \frac{0.4E_i}{D_{m_i} / t_i} \qquad (4.7)$$

where the subscript i corresponds to the member number, E_i is Young's modulus, D_{m_i} is the element's mean diameter, and t_i is the element's wall thickness.

F. DESIGN VARIABLE BOUNDS

Side constraints are imposed on the design variables as:

$$CD_i^{\ell} \leq CD_i \leq CD_i^{u} \qquad (4.3)$$

CD is the characteristic dimension and CD_i^{ℓ} and CD_i^{u} are the minimum and maximum allowable characteristic dimensions of the ith element, and are taken to be the same for all load cases. If, as is the case in a tubular element, geometry dictates that some relationship between the design variables cannot be exceeded, i.e., thickness cannot exceed the mean diameter, the user must arrange the bounds to preclude such an occurrence.

G. OPTIMUM GEOMETRY

Joint coordinates are treated as design variables with a separate design variable for each coordinate direction of a node. Coordinate design variables may also be linked.

IV. PROGRAM FEATURES

A. INTRODUCTION

Computer codes each have their own features and formats with which the user must become familiar if he is to use the code easily and efficiently. The SADX code developed in the course of this research has been designed with various options which are explained in this chapter. Chapter V contains a User's Manual with sample data for a typical problem that might be solved with this code: a truss-braced cantilever beam. This problem along with other numerical examples will be presented in detail with results in Chapter VI.

The SADX code was written to be used as a stand alone analysis program or as an analysis code that could be easily be coupled to an optimizer (of the user's choice) through simple modifications to the main driver program.

B. FEATURES

When the user supplies member areas, section types, characteristic dimensions, material data, connectivities and joint coordinates, along with a set of program control parameters; the analysis mode will calculate the weight of the structure. The addition of one or more sets of loading parameters will result in the calculation of resultant joint

displacements, member stresses, and/or forces for each load case along with the desired number of structure natural frequencies and modes. Design variables may be chosen as truss element areas, frame element characteristic dimensions, and joint coordinates. When coupled to an optimizer, the code will minimize the weight of the structure and print the final optimization information. The code is designed to be as simple to use as possible while retaining the flexibility for use on a variety of problems.

The code's modular construction allows the user to use frame element cross-sections other than tubular elements. This is done by reading in two characteristic dimensions for each frame element along with a section type identifier. Subroutine SADX85 is called to calculate the section properties, area, maximum radial dimensions, and bending and polar moments of inertia. The user may augment this subroutine to calculate section properties for whatever section type he may choose to work with.

Many computer codes require the definition of an auxiliary node to orient the principle axis of a non-axially symmetric element. In this code it is assumed that the element's local z-axis is parallel to the global x-z plane.

Pseudo-dynamic storage is used to allow storage of most data in one integer and one real array for more efficient use of storage.

Various print control options are available to tailor the printed output to match the user's desires.

Design variable linking is available to allow elements and joints to be grouped to maintain symmetry, limit the number of independent design variables, or reduce the variety of member sizes generated.

Optimization may be performed with respect to member size, with respect to structure geometry, or with respect to both.

Structures may be comprised of truss elements, frame elements, or a mix of the two types.

Structures may be optimized for multiple load cases with constraints imposed upon any combination of maximum normal stress, maximum joint displacements and rotations, Euler and local buckling, and a specified number of minimum natural frequencies in free vibration. Separate displacement constraints may be imposed for each load case. Both consistent and lumped mass options are coded. Either forces or stresses or both can be output. The user may decide whether to include the structure's weight and the fixed masses as loads applied to the structure.

C. EXAMPLE

The following example of the truss-braced cantilever beam presented in Tables (I-V) demonstrates some of the options available in the code.

TABLE I

TRUSS-BRACED CANTILEVER BEAM: INPUT CONTROL PARAMETERS

```
INPUT PARAMETERS FOR STRUCTURAL ANALYSIS AND DESIGN
ROUTINE, "SADX"

TRUSS-BRACED CANTILEVER BEAM: EXAMPLE 1

CONTROL PARAMETERS

TOTAL NUMBER OF ELEMENTS,            NE=     4
TOTAL NUMBER OF BAR ELEMENTS,       NEB=     2
TOTAL NUMBER OF FRAME ELEMENTS,     NEF=     2
TOTAL NUMBER OF JOINTS,              NJ=     5
JOINT MAXIMUM DEGREES OF FREEDOM,  JCM=     6
JOINT CONSTRAINT VARIABLE,          NCJ=     3
NUMBER OF MATERIAL TYPES,           NMT=     2
NUMBER OF LOAD CONDITIONS,          NLC=     2
NUMBER OF EIGENVALUES,             NEIG=     1
NO. OF EIGENVALUES CALCULATED,    NEIG1=     2
NUMBER OF FIXED MASSES,          NFMASS=     1
EULER BUCKLING CONSTRAINT ID,     NEUBC=     1
LOCAL BUCKLING CONSTRAINT ID,     LBUCK=     1
NO. OF DISPL. CONSTRAINTS,       NDSPLC=     2
NO. OF FREQ. CONSTRAINTS,         NFREQ=     1
LUMPED MASS OPTION,               LMASS=     0
FORCE/STRESS PRINT OPTION,       NSTRES=     2
OPTIMUM SIZE/BOTH/GEOM OPTION    IDVCLC=     2
STRUCTURE WEIGHT AS LOADS OPTION NSTW=       1
FIXED MASSES AS LOADS OPTION       NFMW=     1

ACCELERATION DUE TO GRAVITY, GRAV         = 0.38640E+03
EIGENVALUE CONVERGENCE TOLERANCE, EPSEIG = 0.10000E-03
```

TABLE II

EXAMPLE 1: JOINT COORDINATE AND MEMBER INPUT DATA

```
JOINT COORDINATES
JOINT         X                        Y                       Z
  1       0.0                     0.0                     0.0
  2       0.10000E+03             0.0                     0.0
  3       0.20000E+03             0.0                     0.0
  4       0.0                     0.15000E+03             0.0
  5       0.0                     0.0                     0.50000E+02
COORDINATE DESIGN VARIABLES
           DESIGN
           VARIABLE              MULTIPLIER
JOINT      X  Y  Z      X                Y                Z
  1        0  0  0      0.0              0.0              0.0
  2        0  0  0      0.0              0.0              0.0
  3        0  0  0      0.0              0.0              0.0
  4        0  1  0      0.1000E+01       0.1000E+01       0.1000E+01
  5        0  0  2      0.1000E+01       0.1000E+01       0.1000E+01


ELEMENT INFORMATION FOR BAR ELEMENTS

ELEMENT-JOINT RELATIONSHIPS

LNO NODE1 NODE2 MATL DVAR1     AREA        LENGTH
 1    2     4     1    1    0.3000E+01  0.1803E+03
 2    2     5     1    2    0.3000E+01  0.1118E+03

ELEMENT INFORMATION FOR FRAME ELEMENTS

ELEMENT-JOINT RELATIONSHIPS   ELEMENT PROPERTIES

ELEMENT NUMBER        3
NODE1   NODE2   MATL   1ST DESVAR 2ND DESVAR
  1       2       2        3          4
  AREA       LENGTH     Z-MOMENT     Y-MOMENT      ZMAX        YMAX
0.157E+02  0.100E+03  0.511E+02   0.511E+02   0.300E+01   0.300E+1

ELEMENT NUMBER        4
NODE1   NODE2   MATL   1ST DESVAR 2ND DESVAR
  2       3       2        3          5
  AREA       LENGTH     Z-MOMENT     Y-MOMENT      ZMAX        YMAX
0.157E+02  0.100E+03  0.511E+02   0.511E+02   0.300E+01   0.300E+1
```

TABLE III

EXAMPLE 1: SAMPLE DISPLACEMENT AND FORCE/STRESS OUTPUT

```
NC. CF EAR ELEPENTS =     2
   LNG  LOAD CCNO  TENSILE FORCE IN X  MAX STRESS
    1       1         -C.73C7E+04       -0.6628E+03
    1       2          0.1549E+04        0.4449E+03
   LNC  LOAD CCND  TENSILE FORCE IN X  MAX STRESS
    2       1          0.7428E+04        0.8740E+03
    2       2         -0.3413E+05       -0.4016E+04
NC. OF FRAME ELEMENTS =     2

ELEMENT  LOAC COND  NCDE  TENSILE FCRCE  SHEAR FORCE   SHEAR FORCE   TORSICN MOMENT  BENDING MCMENT  BENDING MCMENT   MAX
                          IN X DIREX     IN Y DIREX    IN Z DIREX     ABOUT X AXIS   ABCUT Y AXIS    ABCUT Z AXIS    STRESS

   3        1       LCW   -0.1757E+04    0.1066E+04   -0.3395E+01    0.0             0.3395E+C3      0.3515E+05   -0.9632E+04
   3        1       HIGH   0.1757E+04   -0.1066E+04    0.3395E+01    0.0            -0.9766E-03      0.7145E+05    C.1903E+05

   3        2       LCW    0.6647E+04   -0.4187E+03   -0.1482E+04    0.0             0.4816E+C5     -C.1332E+05    0.1447E+05
   3        2       HIGH  -0.6647E+04    0.4187E+03    0.1482E+04    0.0             0.10C0E+C6     -0.2855E+05   -0.279CE+05
ELEMENT  LOAC CCND  NCDE  TENSILE FCRCE  SHEAR FORCE   SHEAR FORCE   TORSICN MOMENT  BENDING MOMENT  BENDING MCMENT   MAX
                          IN X DIREX     IN Y DIREX    IN Z DIREX     ABCUT X AXIS   ABCUT Y AXIS    ABOUT Z AXIS    STRESS

   4        1       LCW   -0.4883E-03   -0.7145E+03   -0.4768E-05    0.0             0.1373E-03     -0.7145E+05   -0.2572E+05
   4        1       HIGH   0.4883E-03    0.7145E+03    0.4768E-05    0.0             0.7324E-03      0.6250E-01    0.2271E-01

   4        2       LCW    0.3906E-02    0.2855E+03    C.1000E+04    0.0            -0.1000E+06      0.2855E+05    0.3600E+05
   4        2       HIGH  -0.3906E-02   -0.2855E+03   -0.1000E+04    0.0            -0.1875E+00     -0.625CE-01   -0.6915E-01
EIGENVALUES ANC EIGENVECTORS

MCOE NUMBER       1
FRECUENCY   = C.41888E+02 CPS
              C.26315E+03 RPS
EIGENVALUE  = C.6927CE+C5
EICENVECTOR   CEGREE CF FREECOM
JCINT            1              2              3
   1      0.0            0.0            0.0
   2      0.0            C.0            0.0
   3     -C.23435E-01   -C.37985E-01   -0.74507E-01
   4     -0.50737E-01   -C.1C745E-01    0.1583CE-03
   5     -C.23435E-01   -0.17155E-01    0.10000E+01


LOAC CCNDITICN      1

DISPLACEMENTS       CEGREE OF FREEDCM
JNT  X-CISPL       Y-CISPL       Z-DISPL      RCT ABT X     RCT ABT Y     ROT ABT Z      T ABT Z
 1    C.C           0.C           0.0          0.0           0.0           0.0           .0
 2   -C.1C5E-03    -0.275E-02    -0.137E-03    C.0           0.206E-05    -0.567E-04     .56646E-04
 3   -0.105E-03    -0.1C5E-01    -0.343E-03    C.0           0.206E-05    -0.875E-04     .87481E-04
 4    0.C           0.C           0.0          0.0           0.0           0.0           .0
 5    C.C           C.C           0.0          0.0           0.0           0.0           .0
LCAC CCNDITICN      2

CISPLACEMENTS       DEGREE CF FREEDOM
JNT  X-CISPL       Y-CISFL       Z-DISPL      ROT ABT X     ROT ABT Y     ROT ABT Z      T ABT Z
 1    C.C           0.C           0.0          0.0           0.0           0.0           .0
 2   -0.226E-03    -0.371E-02    -0.187E-02    0.0           0.416E-04    -0.847E-04     .84689E-04
 3   -C.226E-03    -0.161E-01    -0.784E-02    0.0           0.688E-04    -0.143E-03     .14269E-03
 4    C.C           C.C           0.0          0.0           0.0           0.0           .0
 5    0.0           0.0           0.0          0.0           0.0           0.0           .0
```

TABLE IV

EXAMPLE 1: SAMPLE CONSTRAINT OUTPUT INFORMATION

```
DISPLACEMENT CONSTRAINTS START AT NUMBER   2 AND STOP AT NUMBER   5

TRUSS ELEMENT STRESS CONSTRAINTS
      START AT NUMBER  6 AND STOP AT NUMBER 17

FRAME ELEMENT STRESS CONSTRAINTS
      START AT NUMBER 18 AND STOP AT NUMBER 41

THE NUMBER OF CONSTRAINTS NCTOT =    41

 1) -.408882E+02  -.161055E+01  -.389445E+00  -.258895E+00
 5) -.174111E+01  -.981588E+00  -.101841E+01  -.943857E+00
 9) -.101236E+01  -.987640E+00  -.103769E+01  -.102428E+01
13) -.975722E+00  -.102139E+01  -.888444E+00  -.111156E+01
17) -.901716E+00  -.126755E+01  -.732450E+00  -.152875E+01
21) -.471251E+00  -.118559E+01  -.972695E+00  -.597988E+00
25) -.140201E+01  -.225014E+00  -.177499E+01  -.127432E+01
29) -.959641E+00  -.171444E+01  -.285557E+00  -.100000E+01
33) -.999999E+00  -.123411E+01  -.965558E+00  -.581741E-04
37) -.199994E+01  -.999998E+00  -.100000E+01  -.132766E+01
41) -.951795E+00
```

TABLE V

EXAMPLE 1: FINAL OPTIMIZATION INFORMATION

```
  FINAL OPTIMIZATION INFORMATION

   OBJ =    0.587507E+03

   DECISION VARIABLES (X-VECTOR)
   1) 0.34808E+01  0.84992E+01  0.48389E+01  0.21898E+00  0.15576E+00
   7) 0.45432E+02

   CONSTRAINT VALUES (G-VECTOR)
   1)-0.40888E+02 -0.16106E+01 -0.38945E+00 -0.25889E+00 -0.17411E+01
   7)-0.10184E+01 -0.94336E+00 -0.10124E+01 -0.98764E+00 -0.10377E+01
  13)-0.97572E+00 -0.10214E+01 -0.88844E+00 -0.11116E+01 -0.90172E+00
  19)-0.73245E+00 -0.15287E+01 -0.47125E+00 -0.11856E+01 -0.97270E+00
  25)-0.14020E+01 -0.22501E+00 -0.17750E+01 -0.12743E+01 -0.95964E+00
  31)-0.28556E+00 -0.10000E+01 -0.10000E+01 -0.12341E+01 -0.96556E+00
  37)-0.19999E+01 -0.10000E+01 -0.10000E+01 -0.13277E+01 -0.95180E+00

   THERE ARE     1 ACTIVE CONSTRAINTS
   CONSTRAINT NUMBERS ARE
      36

   THERE ARE     0 VIOLATED CONSTRAINTS

   THERE ARE     0 ACTIVE SIDE CONSTRAINTS

   TERMINATION CRITERION
   ABS(OBJ(I)-OBJ(I-1)) LESS THAN DABFUN FOR 3 ITERATIONS

   NUMBER OF ITERATIONS =   12

   OBJECTIVE FUNCTION WAS EVALUATED           114   TIMES

   CONSTRAINT FUNCTIONS WERE EVALUATED        114   TIMES

   THIS RUN REQUIRED  116  STRUCTURAL ANALYSES

   NUMBER OF SECONDS REQUIRED FOR EXECUTION = 2.79

   WEIGHT OF STRUCTURE GIVEN AREAS & LENGTHS
   WEIGHT=       0.58751E+03

   TOTAL WEIGHT INCLUDING FIXED MASSES
   TOTAL WEIGHT=       0.83751E+03

   JOINT COORDINATES
 JOINT          X                   Y                   Z
    1       0.0                 0.0                 0.0
    2       0.10000E+03         0.0                 0.0
    3       0.20000E+03         0.0                 0.0
    4       0.0                 0.84259E+02         0.0
    5       0.0                 0.0                 0.45432E+02

    ELEMENT INFORMATION FOR BAR ELEMENTS

    ELEMENT-JOINT RELATIONSHIPS

 ELEMENT  NODE 1  NODE 2      AREA          LENGTH
    1        2       4     0.3481E+01     0.1308E+03
    2        2       5     0.8499E+01     0.1098E+03

    ELEMENT INFORMATION FOR FRAME ELEMENTS

    ELEMENT-JOINT RELATIONSHIPS

  LNO NODE1 NODE2    AREA          LENGTH      CHAR.DIM.1   CHAR.DIM.2
   3    1      2  0.3329E+01   0.1000E+03   0.4839E+01   0.2190E+00
   4    2      3  0.2368E+01   0.1000E+03   0.4839E+01   0.1558E+00
```

V. USER GUIDE

A. INTRODUCTION

In developing any computer code for engineering analysis, it is necessary to additionally develop concise, easily understood documentation. This SADX USER'S GUIDE is written to be easily understood by the user having only minimal knowledge of the FORTRAN language. The format follows that of the optimization code, COPES/CONMIN [Ref. 2].

This chapter is devoted to acquainting the user with the code and necessary input data.

B. DESIGN EXAMPLE

The simple example of a four-element combined truss/frame structure is used to demonstrate some of the features of the SADX program.

The structure is shown in Figure 5.1, and consists of two tubular frame elements along the x-axis with two truss braces to the y and z axes from the joint between the frame elements. A non-structural fixed mass is attached at the outboard end of the second frame element where two loads are applied.

C. SADX DATA

The SADX program reads data from unit 5 and writes output on unit 6. Units 30 and 40 are used as scratch files.

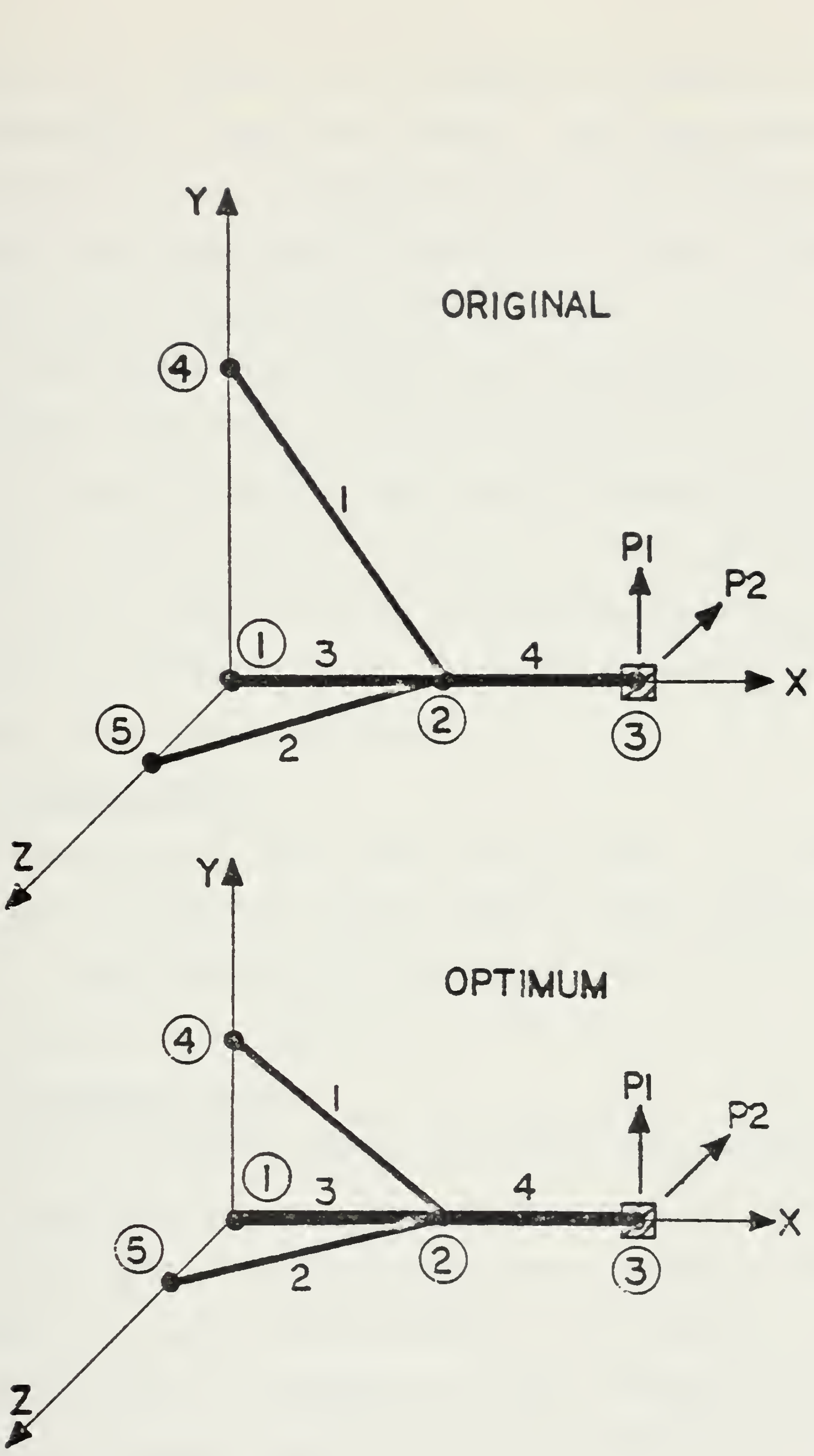

Figure 5.1 TRUSS-BRACED CANTILEVER BEAM

The scratch file numbers may be changed by changing two cards at the beginning of subroutine SADX01. The SADX program has the capability to read unformatted data. The following sections define the data which is required by SADX. The data is segmented into "BLOCKS" for convenience.

SADX data begins with a TITLE card and ends with a END card. Comment cards may be inserted anywhere in the SADX data stack prior to the END card, and are identified by a dollar sign ($) in column 1. Data may be of either the "I10" or "F10.0" type or may be free-format separated by commas with no imbedded blanks. Lines of formatted and unformatted data may be intermixed.

1. Formatted Data

Formats are of "I10" and "F10.0" type. "I" formats must be right justified, and "F" formats must have the decimal point. The number of cards read per data block is listed at the bottom of each block.

2. Unformatted Data

While the USER'S MANUAL data sheet defines SADX data in formatted fields of ten, the data may actually be read in a simplified fashion by separating data by commas or one or more blanks. If more than one number is contained on an unformatted data card, a comma must appear somewhere on the card. If exponential numbers such as 2.5+10 are read on an unformatted card, there must be no imbedded blanks. Unformatted cards may be intermingled with formatted cards. Real numbers on an unformatted card must have a decimal point.

EXAMPLES

Unformatted data

5,7,3.2,1.3+6,-5,2

Equivalent formatted data

col	10	20	30	40	50	60	70	80
	5	7	3.2	1.3+6	-5	0	2	

Unformatted data

2

2,3

2 3

Equivalent formatted data

col	10	20	30	40	50	60	70	80
	2							
	2	3						

2 3

NOTE: The third line of data contains no commas and is therefore assumed to be already formatted.

Placement of more than eight unformatted data on a card will create two (or more) formatted cards as required. Fields of zeros will be created if more data are required than are filled on an unformatted card.

D. CONSTRAINTS

Constraints are calculated and stored in the G vector as listed in the following chart. The total number of constraints

```
NCON=NFREQ+2*NDSPLC+NLC*(2*NEB + 4*NEF + NEB + 2*NEF)
     freq    displ     stress   stress buckl  buckl
```

Where NCON is the total number of constraints, NFREQ is the number of frequency constraints, NDSPLC is the number of displacement constraints, NLC is the number of load cases imposed, NEB is the number of bar or truss elements, and NEF is the number of frame elements. When any of the constraints are missing from the G vector, all constraints are moved up in the vector. For example, if there is no frequency constraint, then a displacement constraint would fill the first location of the G vector.

```
CONSTRAINTS ARE STORED IN THE G VECTOR IN
THE FOLLOWING ORDER:

NFREQ FREQUENCY CONSTRAINTS
2*NDSPLC JOINT DISPLACEMENT CONSTRAINTS
STRESS CONSTRAINTS ARE STORED ELEMENT BY ELEMENT
FOR A GIVEN ELEMENT CONSTRAINTS ARE STORED BY LOAD CASE
FOR A GIVEN TRUSS ELEMENT AND LOAD CASE,
CONSTRAINTS ARE STORED:
    TENSILE STRESS LOWER LIMIT
    TENSILE STRESS UPPER LIMIT
    EULER BUCKLING STRESS LIMIT (IF APPLICABLE)
FOR A GIVEN FRAME ELEMENT AND LOAD CASE,
CONSTRAINTS ARE STORED:
    NORMAL STRESS AT LOW NODE LOWER LIMIT
    NORMAL STRESS AT LOW NODE UPPER LIMIT
    NORMAL STRESS AT HIGH NODE LOWER LIMIT
```

NORMAL STRESS AT HIGH NODE UPPER LIMIT

EULER BUCKLING STRESS LIMIT (IF APPLICABLE)

LOCAL BUCKLING STRESS LIMIT (IF APPLICABLE)

E. EXAMPLE

The initial configuration of the braced cantilever beam is shown in Figure 5.1 Stress constraints are imposed as well as constraints on Euler and local buckling, displacement, and first fundamental frequency. A non-structural fixed mass is applied at the tip of the beam, and two load conditions (P1, and P2) are imposed. The structure's own weight will be considered as an imposed load as will be the fixed mass.

The linking of design variables is demonstrated by linking the mean diameters of the two frame members (D1, and D2 with D1=D2). Member size variables are: truss member areas (A1, and A2), frame member mean diameters (D1, and D2), and frame member thicknesses (T1, and T2). Member sizing DESIGN VARIABLES are: XA(1)=A1, XA(2)=A2, XA(3)=D1=D2, XA(4)=T1, XA(5)=T2.

Geometry variables are the attachment points (joints 4 and 5) of the two truss members on the y and z axes (Y4,Z5). Coordinate DESIGN VARIABLES are: XC(1)=Y4 and XC(2)=Z5. The structure's weight is then optimized with respect to member sizes and structure geometry for a total of seven design variables.

1. Properties/Conditions

Two material types are used: type 1, aluminum, is used for the truss members; and type 2, steel, is used for the frame members. The weight densities of the materials (ρ) are:

type 1 = 0.1 lb/in^3

type 2 = 0.3 lb/in^3

The Young's moduli of the materials (E) are:

type 1 E = 10.0E+6 psi

type 2 E = 29.0E+6 psi

The non-structural fixed mass attached at the tip of the structure weights 250 lb. The applied loads are:

P1	1000.0 lb in the +y direction
P2	1000.0 lb in the -z direction

The acceptable maximum normal stresses are:

type 1 $-25000 \text{ psi} \leq \sigma_{max} \leq 25000 \text{ psi}$

type 2 $-36000 \text{ psi} \leq \sigma_{max} \leq 36000 \text{ psi}$

Displacement limits, imposed upon joint number 3 (the tip) for each load case in the direction of loading, are:

load case 1	y-direction	+/- 3.0 in.
load case 2	z-direction	+/- 3.5 in.

Bounds, placed on the positions of joints 4 and 5 along the y and z axes, are:

joint 4	y-coordinate	0.0 inches to 200.0 inches
joint 5	z-coordinate	0.0 inches to 100.0 inches

The minimum natural frequency of the structure is constrained to be greater than 1Hz.

2. Input Control Parameters

The following input control parameters are given for ease of following the example:

NEB=2
NEF=2
NJ=5
NCJ=3
NMT=2
IDVCLC=2
NDJ=2
NEUBC=1
LBUCK=1
NFREQ=1
NFMASS=1
NEIG=1
NEIG1=2
NPRI=0
NLC=2
NDSPLC=2
NSTRES=2
NSTW=1
NFMW=1

Table VI is a listing of commonly used nomenclature.

The following USER'S MANUAL is divided into blocks A through P. Appearing directly below each data field line are the parameters for the TRUSS-BRACED CANTILEVER BEAM example. It is important to note that the user may choose any consistent system of units.

TABLE VI

COMMON VARIABLE NOMENCLATURE

A - MEMBER'S CROSS-SECTIONAL AREA
BL - LOWER BOUND ON DISPLACEMENTS
BU - UPPER BOUND ON DISPLACEMENTS
CHARDIM1,2- CHARACTERISTIC DIMENSIONS FOR FRAME MEMBERS FOR LSECT.EQ.1: MEAN DIAMETER AND THICKNESS
DIR - DIRECTION 1=X, 2=Y, 3=Z, 4=rot about x, 5=rot about y, 6=rot about z.
E - YOUNGS MODULUS
EPSEIG - CONVERGENCE TOLERANCE OF EIGENVALUE SOLUTIONS (DEFAULT=.0001)
FC1,...FCN- LOWER BOUND ON FIRST,SECOND, ETC. SYSTEM NATURAL FREQUENCY
FX - LOAD FORCES APPLIED IN THE X DIRECTION
FY - LOAD FORCES APPLIED IN THE Y DIRECTION
FZ - LOAD FORCES APPLIED IN THE Z DIRECTION
GRAV - ACCELERATION DUE TO GRAVITY (DEFAULT= 386.4)
IDVCLC - THE OPTIMIZATION OPERATION IDENTIFIER
    1 FOR OPTIMUM MEMBER SIZE ONLY
    2 FOR BOTH OPTIMUM MEMBER SIZE AND GEOMETRY
    3 FOR OPTIMUM GEOMETRY ONLY
IX - CONSTRAINT IDENTIFIER. IF NON-ZERO THE X-DOF IS CONSTRAINED
IY - CONSTRAINT IDENTIFIER. IF NON-ZERO THE Y-DOF IS CONSTRAINED
IZ - CONSTRAINT IDENTIFIER. IF NON-ZERO THE Z-DOF IS CONSTRAINED
IXX - CONSTRAINT IDENTIFIER. IF NON-ZERO THE ROTATION ABOUT THE X-AXIS IS CONSTRAINED
IYY - CONSTRAINT IDENTIFIER. IF NON-ZERO THE ROTATION ABOUT THE Y-AXIS IS CONSTRAINED
IZZ - CONSTRAINT IDENTIFIER. IF NON-ZERO THE ROTATION ABOUT THE Z-AXIS IS CONSTRAINED
JN - JOINT NUMBER (GLOBAL)
    KEULER- EULER BUCKLING COEFFICIENT FOR BAR ELEMENTS
LBUCK - LOCAL BUCKLING CONSTRAINT IDENTIFIER
    IF LBUCK.NE.0, LOCAL BUCKLING CONSTRAINTS WILL BE APPLIED TO TUBULAR FRAME MEMBERS
LC - LOAD CONDITION
LMASS - LUMPED MASS OPTIONS
    IF LMASS.EQ.0 CONSISTENT MASS MATRIX USED
    IF LMASS.NE.0 LUMPED MASS MATRIX USED
LNO - ELEMENT NUMBER
LSECT - CROSS-SECTION TYPE IDENTIFIER
    LSECT.EQ.1 INDICATES A TUBULAR MEMBER
NCJ - THE NUMBER OF CONSTRAINED JOINTS
NDJ - THE NUMBER OF JOINTS WITH (OR LINKED TO) DESIGN VARIABLES
NDSG1 - TRUSS MEMBER AREA DESIGN VARIABLE NUMBER
NDSG2 - COORDINATE DESIGN VARIABLE NUMBER
NDSG3 - FRAME MEMBER CHARACTERISTIC DIMENSION 1 DESIGN VARIABLE NUMBER
NDSG4 - FRAME MEMBER CHARACTERISTIC DIMENSION 2 DESIGN VARIABLE NUMBER

```
NDSPLC     - THE NUMBER OF DISPLACEMENT CONSTRAINT SETS
NEB        - THE NUMBER OF TRUSS ELEMENTS
NEF        - THE NUMBER OF FRAME ELEMENTS
NEIG       - NUMBER OF PRECISE EIGENVALUES TO BE FOUND
NEIG1      - NUMBER OF EIGENVALUE/EIGENVECTOR TO BE
                EVALUATED DEFAULT =MIN(2*NEIG, NEIG+8)
NEUBC      - EULER BUCKLING CONSTRAINT IDENTIFIERS.
                IF NEUBC.NE.0 EULER BUCKLING CONSTRAINTS
                WILL BE IMPOSED ON BAR AND FRAME ELEMENTS
NFMASS     - NUMBER OF NON-STRUCTURAL FIXED MASSES
                ATTACHED TO THE STRUCTURE
NFMW       - FIXED MASS WEIGHT IDENTIFIER
                IF(NFMW.NE.0) FIXED MASSES WILL BE
                CONSIDERED AS LOADS
NFREQ      - NUMBER OF FREQUENCY CONSTRAINTS
NID        - NUMBER OF INDEPENDENT DEGREES OF FREEDOM
NJ         - THE NUMBER OF JOINTS
NLC        - NUMBER OF LOADING CONDTIONS
NLJ        - NUMBER OF LOADED JOINTS FOR THIS LOAD CONDITION
NMT        - NUMBER OF SEPARATE MATERIAL TYPES
NPRI       - INPUT PRINT CONTROL
                IF NPRI.NE.0 INPUT VALUES are NOT PRINTED
                IF NPRI.EQ.5 LOCI/LOCR/IA/RA ARRAYS PRINTED
NSTRES     - THE FORCE/STRESS PRINT IDENTIFIER
                IF NSTRES.EQ.0 MEMBER FORCES PRINTED
                IF NSTRES.EQ.1 MEMBER STRESSES PRINTED
                IF NSTRES.EQ.2 BOTH are PRINTED
NSTW       - STRUCTURE WEIGHT IDENTIFIER
                if(NSTW.NE.0) THE STRUCTURE'S OWN WEIGHT
                WILL BE CONSIDERED AS LOADS
POISSN     - POISSON'S RATIO
RHO        - MATERIAL WEIGHT DENSITY
SIGMIN     - MINIMUM ALLOWABLE NORMAL STRESS
SIGMAX     - MAXIMUM ALLOWABLE NORMAL STRESS
TX         - TORSIONAL MOMENT APPLIED ABOUT THE X-AXIS
TY         - TORSIONAL MOMENT APPLIED ABOUT THE Y-AXIS
TZ         - TORSIONAL MOMENT APPLIED ABOUT THE Z-AXIS
XA         - INITIAL VALUE OF AREA DESIGN VARIABLE
XAL        - LOWER BOUNDS ON XA
XAU        - UPPER BOUNDS ON XA
XC         - INITIAL VALUE OF COORDINATE DESIGN VARIABLE
XCL        - LOWER BOUNDS ON XC
XCU        - UPPER BOUNDS ON XC
```

DATA BLOCK A

DESCRIPTION: Title Card

Format and Example

TITLE	FORMAT 20A4
TRUSS-BRACED CANTILEVER BEAM	

FIELD	CONTENTS
1	ANY 80 CHARACTER TITLE MAY BE GIVEN ON THIS LINE

DATA BLOCK B

DESCRIPTION: Control Parameters

Format and Example

NEB	NEF	NJ	NCJ	NMT	IDVCLC	NDJ	FORMAT 7I10
2	2	5	3	2	2	2	

NEUBC	LBUCK	NFREQ	NFMASS	NEIG	NEIG1	NPRI	format 7I10
1	1	1	1	1	2	0	

NLC	NDSPLC	NSTRES	NSTW	NFMW		FORMAT 5I10
2	2	2	1	1		

NOTE: DEFINITIONS OF PROGRAM INPUT CONTROL PARAMETERS ARE LISTED ON NEXT PAGE

FIELD	CONTENT
	FIRST CARD
1	NEB-number of bar elements
2	NEF-number of frame elements
3	NJ-number of joints
4	NCJ-number of constrained joints
5	NMT-number of seperate material types

6	IDVCLC-design variable control parameter
	If (IDVCLC.EQ.1) NDV=NDVAR1
	optimizes wrt member size only
	If (IDVCLC.EQ.2) NDV=NDVAR1+ NDVAR2
	optimizes wrt member size and geometry
	If (IDVCLC.EQ.3) NDV=NDVAR2
	optimizes wrt geometry only

7	NDJ-total linked and design variable joints (i.e. number of 'movable' joints)
	SECOND CARD
1	NEUBC-Euler buckling constraint identifier If (NEUBC.NE.0) EULER buckling constraints will be imposed on bar elements
2	LBUCK-local buckling constraint identifier If (LBUCK.NE.0) local buckling constraints will be imposed on tubular frame elements
3	NFREQ-number of frequency constraints
4	NFMASS-number of fixed masses attached to structure
5	NEIG-number of precise eigenvalues to be evaluated

6 NEIG1-number of eigenvalues to be evaluated
DEFAULT=min. of (2*NEIG , NEIG+8)

7 NPR1-print control identifier
NPR1.ne.0 input info not printed
NPR1.eq.5 RA/IA/LOCR/LOCI arrays
will be printed for debugging

THIRD CARD

1 NLC-number of load conditions

2 NDSPLC-number of displacement constraints

3 NSTRES-force/stress print identifier
If (NSTRES.EQ.0) stresses are printed
If (NSTRES.EQ.1) forces are printed
If (NSTRES.EQ.2) both are printed

4 NSTW-structure weight identifier
If (NSTW.NE.0) the structure's weight is
considered as loads

5 NFMW-fixed mass weight identifier
If (NFMW.NE.0) the fixed masses are
considered as loads

DATA BLOCK C

DESCRIPTION: Dynamic Analysis Information

Format and Example

LMASS	GRAV	EPSEIG		FORMAT
				I10,2F10.0

0	386.4	0.0

FIELD	CONTENTS
1	LMASS-lumped mass option (if LMASS.NE.0) the lumped mass matrix is used.
2	GRAV-accleration due to gravity (default=386.4 inches/sec^2)
3	EPSEIG-convergence tolerance on eigenvalue solution. (default=.0001)

DATA BLOCK D

DESCRIPTION: Joint Coordinates

Format and Example

JN	X	Y	Z		FORMAT I10,3F10.0
1	0.0	0.0	0.0		
2	100.0	0.0	0.0		
3	200.0	0.0	0.0		
4	0.0	150.0	0.0		
5	0.0	0.0	50.0		

FIELD	CONTENTS
1	JN-joint coordinate number
2	X-x coordinate
3	Y-y coordinate
4	Z-z coordinate

NOTE: Number of cards read=NJ

DATA BLOCK E

Omit this block if NDJ=0 in BLOCK B

DESCRIPTION: Coordinate Design Variable Linking Data

Format and Example

JN	IX	IY	IZ	PCX	PCY	PCZ	FORMAT 4i10,3f10.0
4	0	1	0	1.0	1.0	1.0	
5	0	0	2	1.0	1.0	1.0	

FIELD	CONTENTS
1	IX-design variable associated with x coord.
2	IY-design variable associated with y coord.
3	IZ-design variable associated with z coord.
4	PCX-participation coefficient of x-coord.
5	PCY-participation coefficient of y-coord.
6	PCZ-participation coefficient of z-coord.

NOTE: Number of cards read=NDJ

DATA BLOCK F

DESCRIPTION: Material Properties

Format and Example

E	RHO	SIGMIN	SIGMAX	KEULER	POISSN	FORMAT 6F10.0

1.0E+7	0.1	-25000.	25000.	2.0	0.27

2.9E+7	0.3	-36000.	36000.	2.0	0.27

FIELD	CONTENTS
1	E-Young's Modulus
2	RHO-material density
3	SIGMIN-minimum allowable stress
4	SIGMAX-maximum allowable stress
5	KEULER-Euler buckling coefficient
6	POISSN-Poisson's ratio

NOTE: Number of cards read=NMT

DATA BLOCK G

Omit this block if NEB=0 in BLOCK B

DESCRIPTION: Bar Element Information

Format and Example

LNC	NODE1	NODE2	MATCOD	NDSG1	A	LSECT	FORMAT
							5I10 f10,I10
3	2	4	1	1	3.0	1	
2	2	5	1	2	3.0	1	

FIELD	CONTENTS
1	LNO-element number
2	NODE1-global number associated with the element's 1st node
3	NODE2-global number associated with the element's 2nd node
4	MATCOD-material type of this element
5	NDSG1-design variable number associated with this element's area
6	A-member cross-sectional area
7	LSECT-cross-section type identifier LSECT.EQ.1 indicates a tubular member

NOTE: Number of cards read=NEB

DATA BLOCK H

Omit this block if NEF=0 in BLOCK B

DESCRIPTION: Frame Element Information Format and Example

LNO	NODE1	NODE2	MATCOD	NDSG3	NDSG4	LSECT	FORMAT 7I10

3	1	2	2	2	4	1

CHARDIM1	CHARDIM2		FORMAT 2F10

5.0	1.0

4	2	3	2	3	5	1

5.0	1.0

FIELD	CONTENTS
1	LNO-element number
2	NODE1-global number associated with the element's 1st node
3	NODE2-global number associated with the element's 2nd node
4	MATCOD-material type of this element
5	NDSG3-design variable number associated with the element's 1st characteristic dimension
6	NDSG4-design variable number associated with the element's 2nd characteristic dimension
7	LSECT-cross-section type identifier LSECT.EQ.1 indicates a tubular member

NOTE: Number of cards read=NEF

DATA BLOCK I

DESCRIPTION: Joint Constraint Information

Format and Example

JN	IX	IY	IZ	IXX	IYY	IZZ	FORMAT 7I10
1	1	1	1	1	1	1	
2	0	0	0	0	0	0	
3	0	0	0	0	0	0	
4	1	1	1	1	1	1	
5	1	1	1	1	1	1	

FIELD	CONTENTS
1	JN-joint number
2	IX- x-displacement constraint identifier.
3	IY- y-displacement constraint identifier.
4	IZ- z-displacement constraint identifier.
5	IXX- x-axis rotation constraint identifier.
6	IYY- y-axis rotation constraint identifier.
7	IZZ- z-axis rotation constraint identifier. if .NE.0 - corresponding DOF constrained

NOTE: Number of cards read=NCJ

DATA BLOCK J

Omit this block if NLC=0 in BLOCK B.

DESCRIPTION: Joint Loading Information

Format and Example

NLJ		FORMAT I10

1

JN	FX	FY	FZ	TX	TY	TZ	FORMAT I10,6F10

2	0.0	1000.	0.0	0.0	0.0	0.0

1

2	0.0	0.0	-1000.	0.0	0.0	0.0

FIELD	CONTENT
1	NLJ-number of loaded joints for this load condition
1	JN-joint number
2	FX
3	FY- Forces in the X,Y,Z directions
4	FZ
5	TX
6	TY- Moments about the X,Y,Z axes
7	TZ

NOTE: Number of cards read per set=NLJ
Number of sets of cards read=NLC

DATA BLOCK K

Omit this block if NFMASS=0 in BLOCK B

DESCRIPTION: Fixed Mass Information

Format and Example

JN	MASS		FORMAT I10,F10

3	250.0

FIELD	CONTENTS
1	JN-joint number
2	MASS-point mass at joint (JN) in force units

NOTE: Number of cards read=NFMASS

DATA BLOCK L

Omit this block if IDVCLC=3

DESCRIPTION: Design Variable Information
(MEMBER SIZE VARIABLES)

Format and Example

XA(1)	XA(2)	. . . . XA(NDVAR1)	FORMAT 8F10.0

20.0	20.0	20.0	2.0	2.0

XAL(1)	XAL(2)	. . . .XAL(NDVAR1)	FORMAT 8F10.0

0.50	0.50	4.0	0.10	0.10

XAU(1)	XAU(2)	. . . .XAU(NDVAR1)	FORMAT 8F10.0

25.0	35.0	25.0	2.5	4.0

FIELD	CONTENTS
1	XA-initial value of area design variables
2	XAL-lower bounds on area design variables
3	XAU-upper bounds on area design variables

NOTE: read one value of XA, XAL, XAU for each independent member size variable defined in BLOCKS G and H

Number of cards read = as required

DATA BLOCK M

Omit this block if IDVCLC=1

DESCRIPTION: Design Variable Information
(COORDINATE VARIABLES)

Format and Example

XC(1)	XC(2)	. . . . XC(NDVAR2)	FORMAT 8F10.0

150.0	50.0

XCL(1)	XCL(2)	. . . .XCL(NDVAR2)	FORMAT 8F10.0

0.0	0.0

XCU(1)	XCU(2)	. . . .XCU(NDVAR2)	FORMAT 8F10.0

200.0	100.0

FIELD	CONTENTS
1	XC-initial value of coord. design variables
2	XCL-lower bounds on coord. design variables
3	XCU-upper bounds on coord. design variables

NOTE: read one value of XC,XCL,XCU for each independent coord. variable defined in BLOCK D

Number of cards read =as required.

DATA BLOCK N

Omit this block if NDSPLC=0 in BLOCK B

DESCRIPTION: Joint Displacement Constraint Information

Format and Example

JN	DIR	LC	BL	BU	FORMAT 3I10,2F10.0
3	2	1	-3.0	3.0	
3	3	2	-3.5	3.5	

FIELD	CONTENTS
1	JN-joint number
2	DIR-direction 1=x,2=y,3=z displacement 4=x,5=y,6=z rotation
3	LC-load condition
4	BL-lower bound on displacement
5	BU-upper bound on displacement

NOTE: Number of cards read= NDSPLC

DATA BLOCK O

Omit this block if NFREQ=0 in BLOCK B

DESCRIPTION: Frequency Constraint Information

Format and Example

FC1	FC2	FC3	.......FCN	FORMAT 8F10.0

1.0

FIELD	CONTENTS
1	FC1- lower bound on first natural frequency constraint in Hz. (cycles per second)
N	FCN- lower bound on NFREQ-th natural frequency constraint in Hz. (cycles per second)

NOTE: Number of cards read = as required

DATA BLOCK P

DESCRIPTION: End card

Format and Example

END		FORMAT 3A1

END

NOTE: This card MUST appear at the end of the SADX data.

VI. NUMERICAL EXAMPLES

A. INTRODUCTION

Design of three-dimensional truss and frame structures are presented herein and the corresponding numerical results are summarized to demonstrate the use of the SADX code.

The examples begin with the truss-braced cantiliver beam.

B. EXAMPLE 1: TRUSS-BRACED CANTILIVER BEAM

The simple truss-braced cantiliver beam, as shown in Figure 6.1, has been previously used for the SADX USER's MANUAL example. It consists of two steel tubular frame members with a common outer diameter and different wall thicknesses arranged as a cantilever beam along the X-axis. There is a fixed 250 pound mass at the tip of the beam. Two aluminum truss members are attached from the beam mid-point to points on the Y and Z axes. This structure is designed for optimum member size and geometry under a set of two load conditions and subject to constraints on maximum stress, maximum joint displacement, Euler and local buckling, and minimum structure natural frequencies. The weight of the non-structural fixed mass and the structure's own weight are imposed as loads. There are five member size and two coordinate design variables, and a total of 41 constraints.

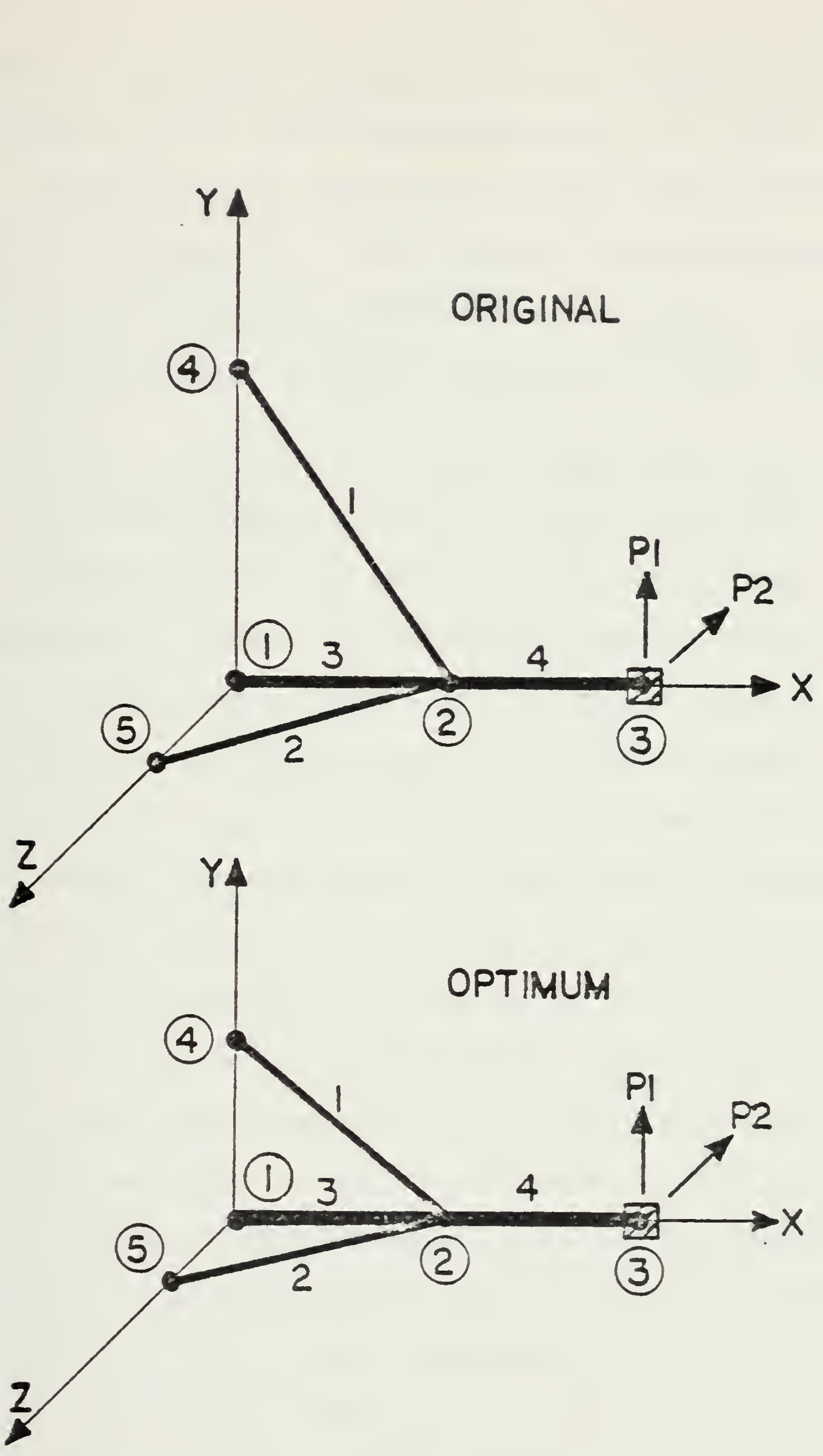

Figure 6.1 TRUSS-BRACED CANTILEVER BEAM

The number of analyses required for this design is 116 using 2.75 seconds of CPU time and terminating on the 12th iteration. Of the analyses conducted, 84 were required for the calculation of gradients. The weight of the structure, including non-structural fixed masses, is reduced from 9542 pounds to 838 pounds. Results are given in Table VII.

C. EXAMPLE 2: TWO-TIER 3-D PORTAL FRAME WITH TRUSS X-BRACES

The two-tier three-dimensional portal frame with truss member diagonal braces, as shown in Figure 6.2, is a symmetric moderately sized case that can be analyzed easily by a variety of other codes. There are 20 truss elements, 16 frame elements, and four non-structural fixed masses. The material used is steel. This structure is designed for optimum member size and geometry under a set of three load conditions and subject to constraints on maximum stress, maximum joint displacement, Euler and local buckling, and minimum structure natural frequencies. The weight of the non-structural fixed masses and the structure's own weight are imposed as loads. There are 10 member size and five coordinate design variables and a total of 493 constraints. The number of analyses required for this design is 385 using 120 seconds of CPU time and terminating on the 21st iteration. Of the analyses conducted, 305 were required for the calculation of gradients. The weight of the structure, including non-structural fixed masses, is reduced from 9302 pounds to 1462 pounds. Results are given in Table VIII.

TABLE VII

EXAMPLE 1: FINAL OPTIMIZATION INFORMATION

```
   FINAL OPTIMIZATION INFORMATION

    OBJ =    0.587507E+03

    THERE ARE     1 ACTIVE CONSTRAINTS
    CONSTRAINT NUMBERS ARE
       36

    THERE ARE     0 VIOLATED CONSTRAINTS

    THERE ARE     0 ACTIVE SIDE CONSTRAINTS

    TERMINATION CRITERION
    ABS(OBJ(I)-OBJ(I-1)) LESS THAN DABFUN FOR 3 ITERATIONS

    NUMBER OF ITERATIONS =   12

    OBJECTIVE FUNCTION WAS EVALUATED           114  TIMES

    CONSTRAINT FUNCTIONS WERE EVALUATED        114  TIMES

    THIS RUN REQUIRED  116  STRUCTURAL ANALYSES

    NUMBER OF SECONDS REQUIRED FOR EXECUTION = 2.79

    WEIGHT OF STRUCTURE GIVEN AREAS & LENGTHS
    WEIGHT=     0.58751E+03

    TOTAL WEIGHT INCLUDING FIXED MASSES
    TOTAL WEIGHT=     0.83751E+03

    JOINT COORDINATES
JOINT           X                  Y                  Z
   1      0.0               0.0               0.0
   2      0.10000E+03       0.0               0.0
   3      0.20000E+03       0.0               0.0
   4      0.0               0.84259E+02       0.0
   5      0.0               0.0               0.45432E+02

    ELEMENT INFORMATION FOR BAR ELEMENTS

    ELEMENT-JOINT RELATIONSHIPS

ELEMENT  NODE 1  NODE 2      AREA          LENGTH
   1        2       4     0.3481E+01    0.1308E+03
   2        2       5     0.8499E+01    0.1098E+03

    ELEMENT INFORMATION FOR FRAME ELEMENTS

    ELEMENT-JOINT RELATIONSHIPS

  LNC NODE1 NODE2   AREA        LENGTH      CHAR.DIM.1  CHAR.DIM.2
   3    1     2  0.3329E+01  0.1000E+03  0.4839E+01  0.2190E+00
   4    2     3  0.2368E+01  0.1000E+03  0.4839E+01  0.1558E+00

EIGENVALUES AND EIGENVECTORS

MODE NUMBER     1
FREQUENCY  =  0.41888E+02 CPS
              0.26319E+03 RPS
EIGENVALUE =  0.69270E+05
EIGENVECTOR   DEGREE OF FREEDOM
JOINT          1                   2                  3
   1     0.0               0.0               0.0
   2     0.0               0.0               0.0
   3    -0.23435E-01      -0.33985E-01      -0.74507E-01
   4    -0.50777E-01      -0.10745E-01       0.15830E-03
   5    -0.23435E-01      -0.17155E-01       0.10000E+01
```

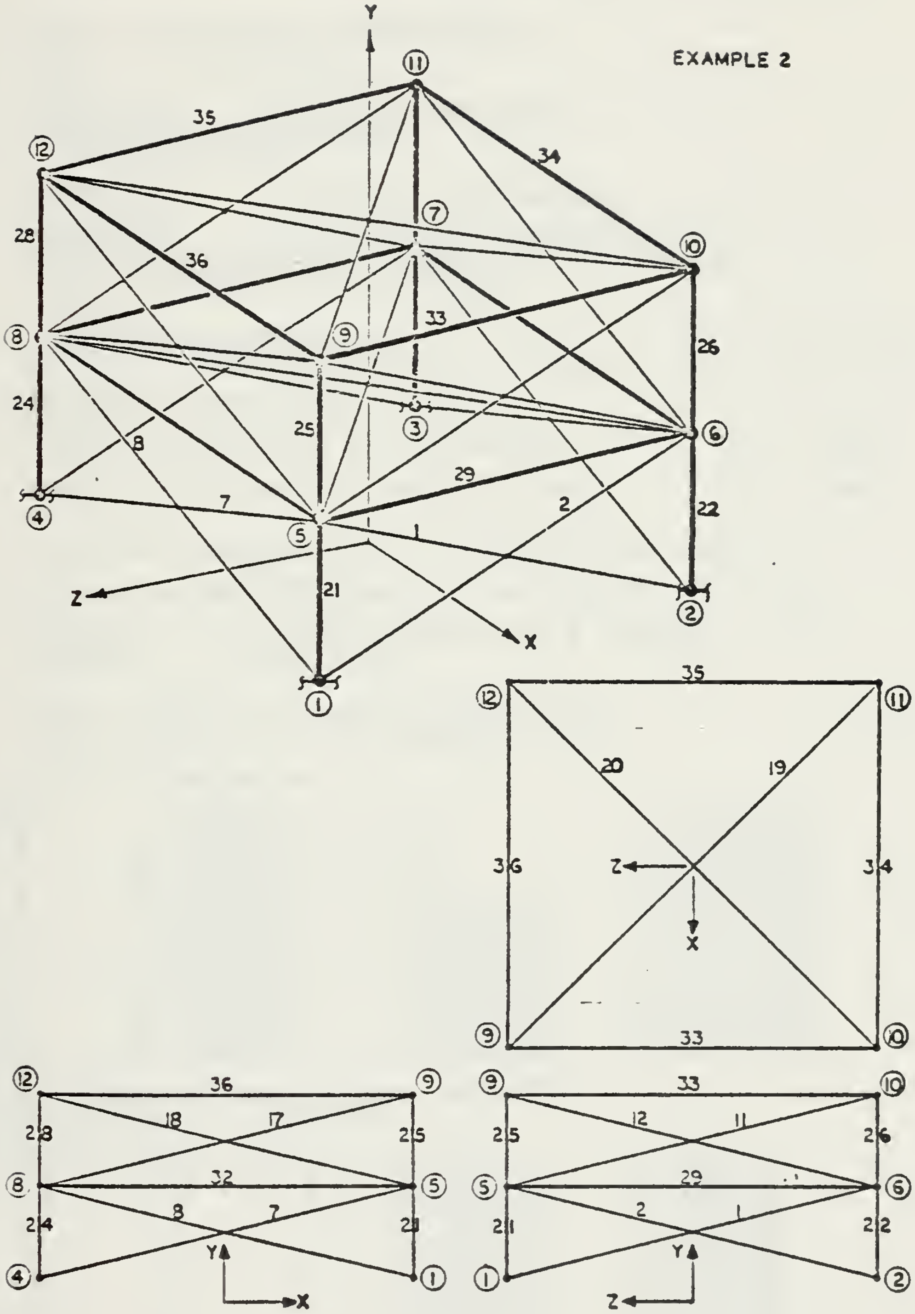

Figure 6.2 TWO-TIER 3-D PORTAL FRAME WITH TRUSS X-BRACES

TABLE VIII

EXAMPLE 2: FINAL OPTIMIZATION INFORMATION

```
    FINAL OPTIMIZATION INFORMATION

    OBJ =    0.144183E+04

    THERE ARE    3 ACTIVE CONSTRAINTS
    CONSTRAINT NUMBERS ARE
       46   91  196

    THERE ARE    0 VIOLATED CONSTRAINTS

    THERE ARE    1 ACTIVE SIDE CONSTRAINTS
    DECISION VARIABLES AT LOWER OR UPPER BOUNDS
    (MINUS INDICATES LOWER BOUND)
      -14

    TERMINATION CRITERION
    ABS(OBJ(I)-OBJ(I-1)) LESS THAN DABFUN FOR 3 ITERATIONS

    NUMBER OF ITERATIONS =   21

    OBJECTIVE FUNCTION WAS EVALUATED              383  TIMES

    CONSTRAINT FUNCTIONS WERE EVALUATED           383  TIMES

    THIS RUN REQUIRED  385  STRUCTURAL ANALYSES

    NUMBER OF SECONDS REQUIRED FOR EXECUTION = 120.7

    WEIGHT OF STRUCTURE GIVEN AREAS & LENGTHS
    WEIGHT=      0.14418E+04

    TOTAL WEIGHT INCLUDING FIXED MASSES
    TOTAL WEIGHT=      0.16418E+04

    JOINT COORDINATES
JOINT           X                   Y                   Z
   1       0.63385E+02      0.0                  0.90002E+02
   2       0.63385E+02      0.0                 -0.90002E+02
   3      -0.63385E+02      0.0                 -0.90002E+02
   4      -0.63385E+02      0.0                  0.90002E+02
   5       0.80239E+02      0.20000E+02          0.69074E+02
   6       0.80239E+02      0.20000E+02         -0.69074E+02
   7      -0.80239E+02      0.20000E+02         -0.69074E+02
   8      -0.80239E+02      0.20000E+02          0.69074E+02
   9       0.10000E+03      0.10000E+03          0.10000E+03
  10       0.10000E+03      0.10000E+03         -0.10000E+03
  11      -0.10000E+03      0.10000E+03         -0.10000E+03
  12      -0.10000E+03      0.10000E+03          0.10000E+03

ELEMENT INFORMATION FOR BAR ELEMENTS
ELEMENT-JOINT RELATIONSHIPS

ELEMENT   NODE 1   NODE 2       AREA            LENGTH
    1        1        6      0.4255E+00      0.1612E+03
    2        2        5      0.4255E+00      0.1612E+03
    3        2        7      0.4255E+00      0.1465E+03
    4        3        6      0.4255E+00      0.1465E+03
    5        3        8      0.4255E+00      0.1612E+03
    6        4        7      0.4255E+00      0.1612E+03
    7        4        5      0.4255E+00      0.1465E+03
    8        1        8      0.4255E+00      0.1465E+03
    9        5        7      0.4255E+00      0.2118E+03
   10        6        8      0.4255E+00      0.2118E+03
   11        5       10      0.1544E+01      0.1881E+03
   12        6        9      0.1544E+01      0.1881E+03
   13        6       11      0.1544E+01      0.1996E+03
```

D. EXAMPLE 3: DD-963 FOREMAST

Example three is a redesign of the forward mast on the DD-963 of SPRUANCE class destroyer. The DD-963 foremast has been chosen as the third test case for the following reasons: 1) the structure is typical of the masts found on many combatants in the United States and other navies, 2) high topside weight reduction is desirable from a stability viewpoint for any ship, 3) the structural members are predominantly tubular, 4) the problem is sufficiently complex to make conventional design methods cumbersome, 5) the member size and loading information is available.

The structure as shown in Figures 6.3 through 6.6 is constructed of 172 aluminum frame members. The material used in the structure is 5086 H32 aluminum, an alloy with moderate strength, good weldability, and good corrosion resistance.

This structure is designed for optimum member size under a single load condition and subject to constraints on maximum member stress, maximum joint displacement, Euler and local buckling.

Some structural simplifications are made. The weights of mast-mounted radars, antennas, and platforms are modeled by a series of fixed masses which are imposed as loads along with the structure's own weight. The forces due to halyards and wire antennas are applied as loads. Inertial forces due to ships motion are calculated for the initial design point

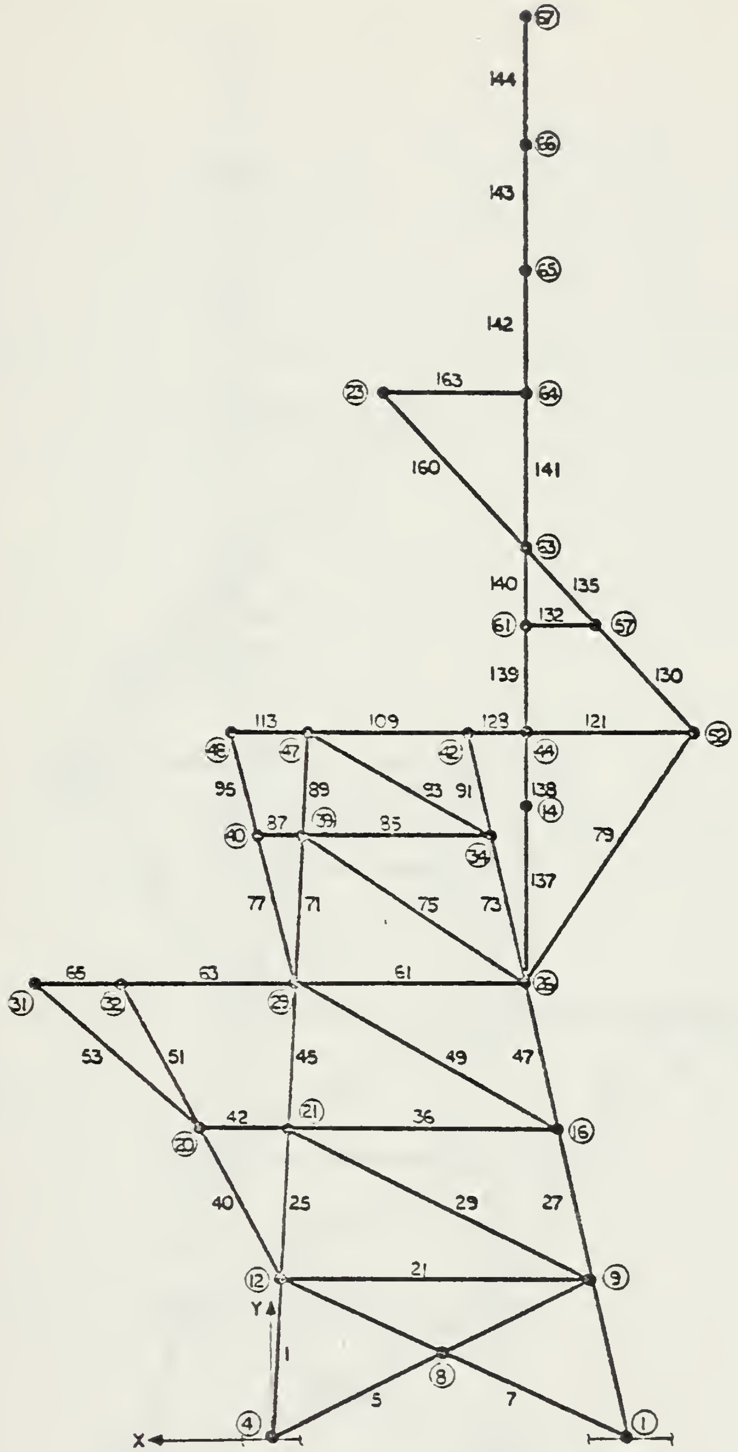

Figure 6.3 DD-963 FOREMAST PORT SIDE

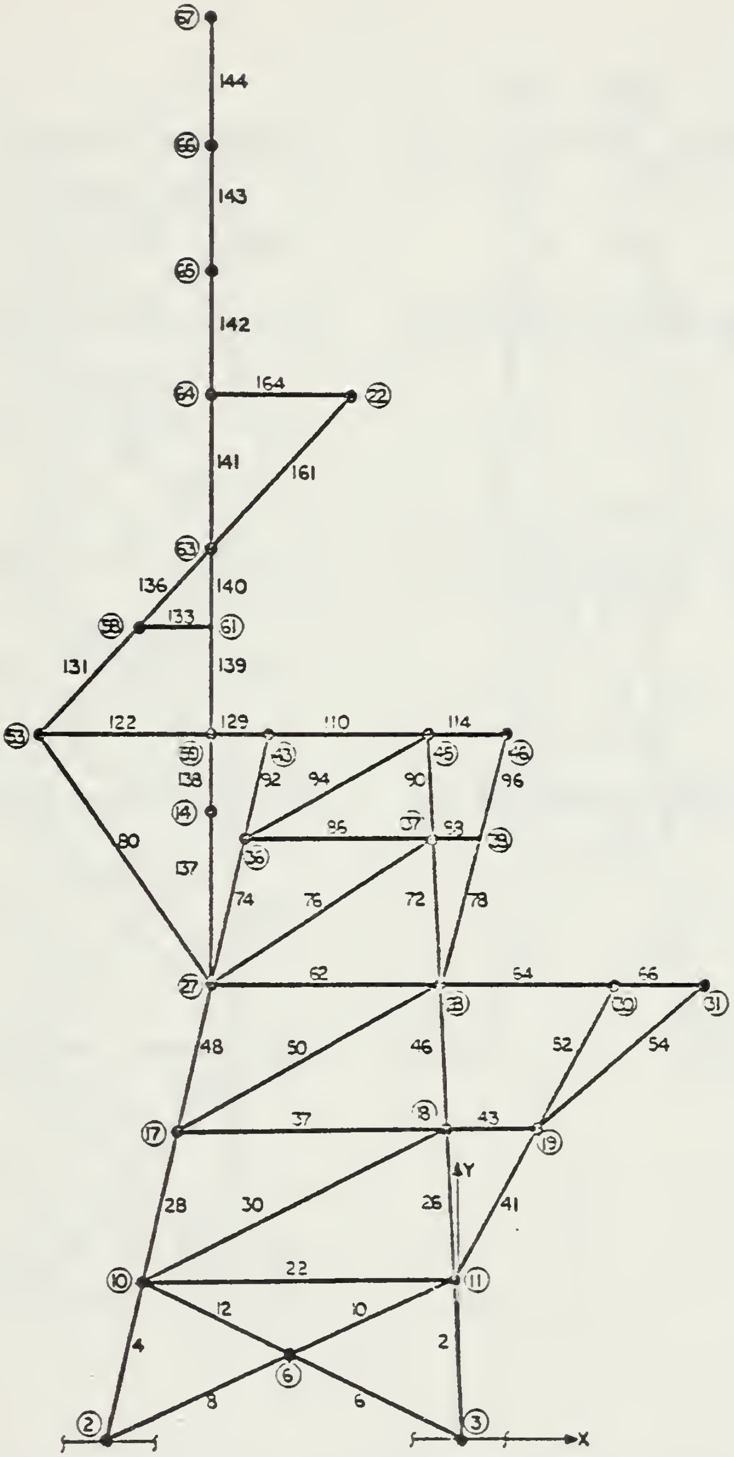

Figure 6.4 DD-963 FOREMAST STARBOARD SIDE

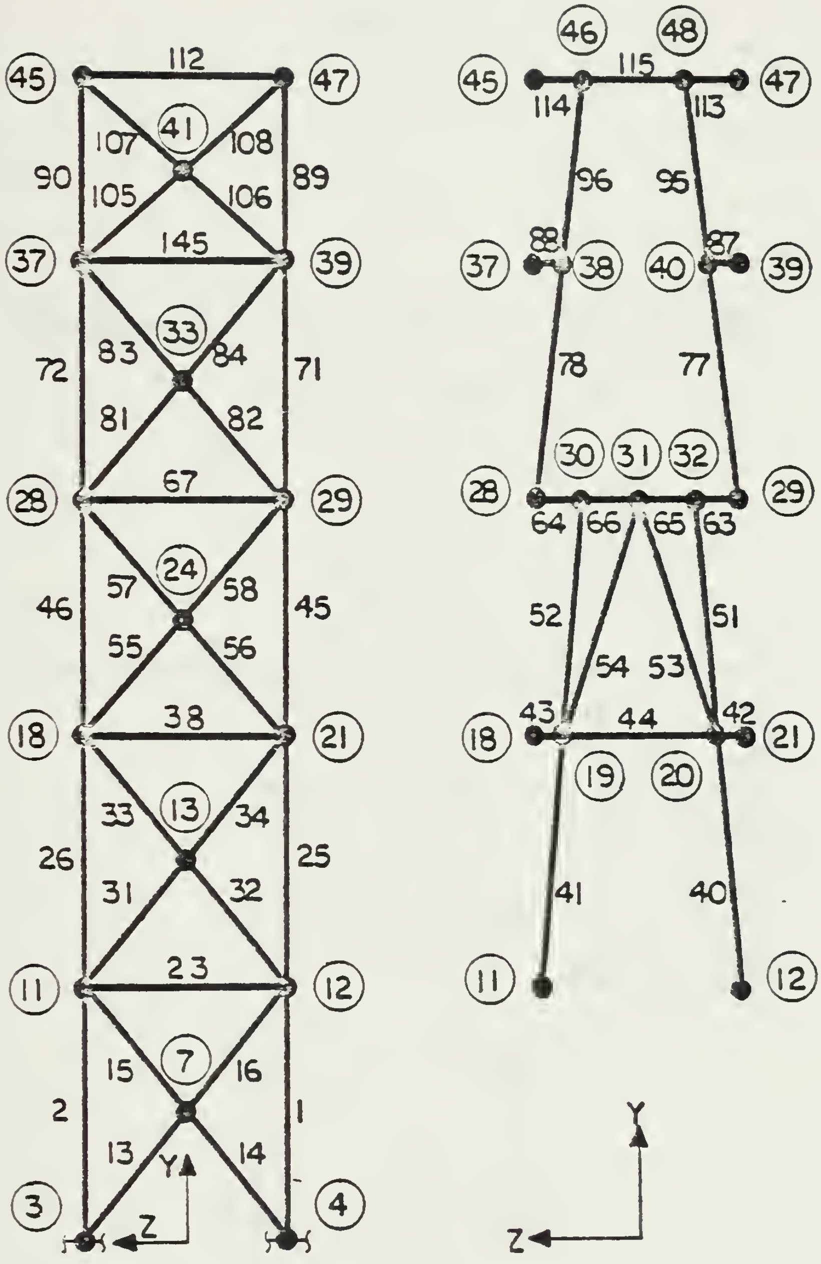

Figure 6.5 DD-963 FOREMAST FORWARD SIDE

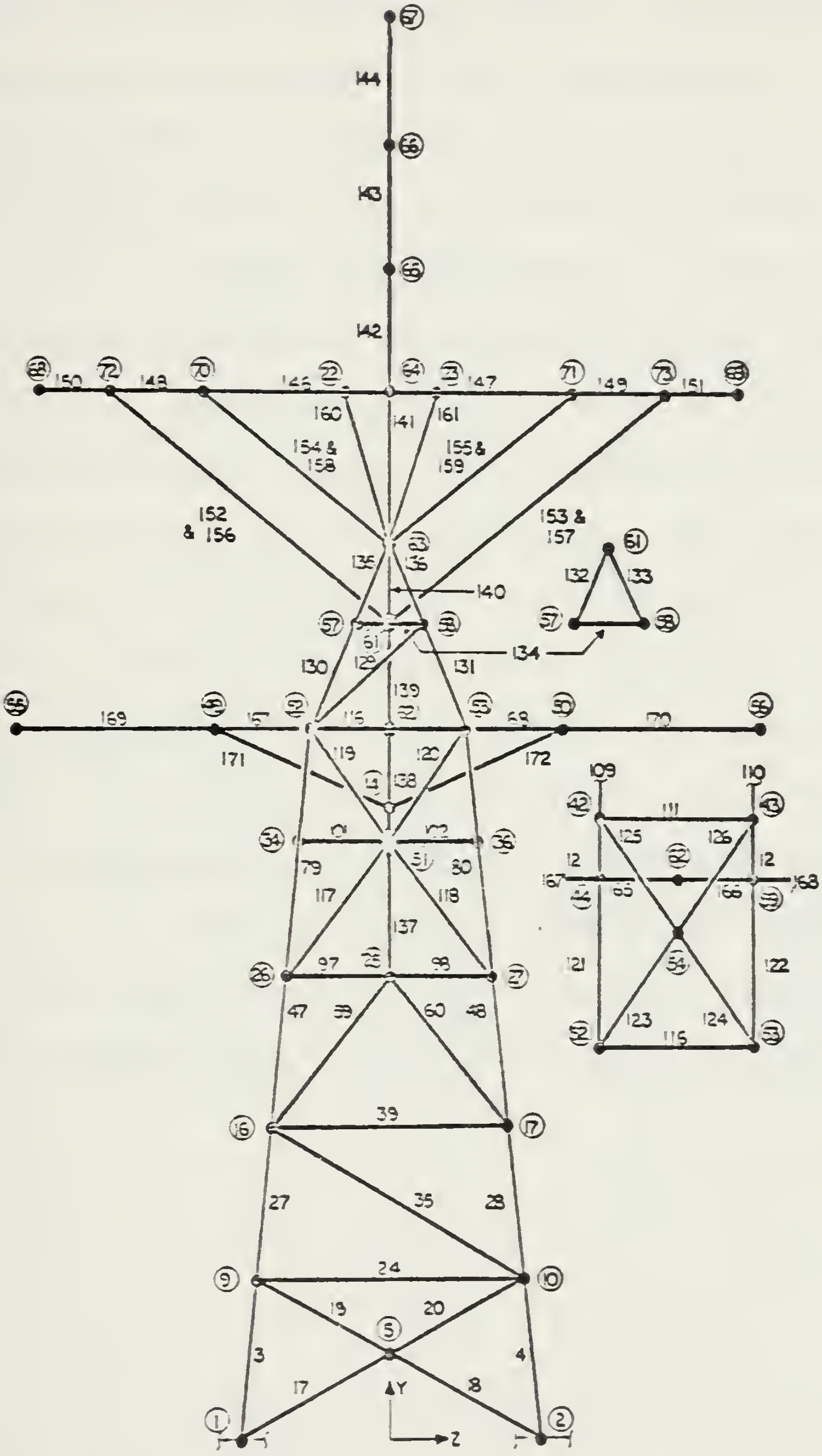

Figure 6.6 DD-963 FOREMAST AFT SIDE

and consist of the product of a member's half-weight and a coordinate-dependent load-factor applied at each end of the element [Ref. 6]. The load-factor multiplier is dependent on the distances from a point at the intersection of the design waterline and the ship centerline amidships (frame 264 1/2). Ship's motion loads are applied for a roll to port. In that the purpose of this example is only to attempt to solve a large and messy problem rather than to produce an actual design no attempt is made to include wind, shock, and blast loads. There are 34 member size design variables and a total of 1054 constraints. The number of analyses required for this design is 555 using 4482 seconds of CPU time and terminating on the 17th iteration. Of the analyses conducted, 544 were required for the calculation of gradients. The weight of the structure, including non-structural fixed masses, is increased from 48,199 pounds to 56,746 pounds. The structure as modeled was initially infeasible due, most likely to the structural simplifications made in the topmast area. Results are given in Table IX.

TABLE IX

EXAMPLE 3: FINAL OPTIMIZATION INFORMATION

```
FINAL OPTIMIZATION INFORMATION

OBJ =    0.398604E+05

THERE ARE    2 ACTIVE CONSTRAINTS
CONSTRAINT NUMBERS ARE
  860  866

THERE ARE    0 VIOLATED CONSTRAINTS

THERE ARE    0 ACTIVE SIDE CONSTRAINTS

TERMINATION CRITERION
ABS(OBJ(I)-OBJ(I-1) LESS THAN DABFUN FOR 3 ITERATIONS

NUMBER OF ITERATIONS =    17

OBJECTIVE FUNCTION WAS EVALUATED          553  TIMES

CONSTRAINT FUNCTIONS WERE EVALUATED       553  TIMES

THIS RUN REQUIRED  555  STRUCTURAL ANALYSES

WEIGHT OF STRUCTURE GIVEN AREAS & LENGTHS
WEIGHT=      0.39860E+05

TOTAL WEIGHT INCLUDING FIXED MASSES
TOTAL WEIGHT=      0.56746E+05

NUMBER OF SECONDS REQUIRED FOR EXECUTION = 4482.46

NO. OF FRAME ELEMENTS =  172
ELEMENT-JOINT RELATIONSHIPS

LNO NODE1 NODE2    AREA         LENGTH       CHAR.DIM.1    CHAR.DIM.2
  1    4    12   0.5979E+02   0.1081E+03   0.1900E+02   0.1002E+01
  2    3    11   0.5979E+02   0.1081E+03   0.1900E+02   0.1002E+01
  3    1     9   0.5979E+02   0.1112E+03   0.1900E+02   0.1002E+01
  4    2    10   0.5979E+02   0.1112E+03   0.1900E+02   0.1002E+01
  5    4     8   0.6247E+01   0.1342E+03   0.6563E+01   0.3030E+00
  6    3     6   0.6247E+01   0.1342E+03   0.6563E+01   0.3030E+00
  7    1     8   0.6247E+01   0.1369E+03   0.6563E+01   0.3030E+00
  8    2     6   0.6247E+01   0.1369E+03   0.6563E+01   0.3030E+00
  9    8    12   0.6247E+01   0.1295E+03   0.6563E+01   0.3030E+00
 10    6    11   0.6247E+01   0.1295E+03   0.6563E+01   0.3030E+00
 11    8     9   0.6247E+01   0.1132E+03   0.6563E+01   0.3030E+00
 12    6    10   0.6247E+01   0.1132E+03   0.6563E+01   0.3030E+00
 13    3     7   0.6247E+01   0.6846E+02   0.6563E+01   0.3030E+00
 14    4     7   0.6247E+01   0.6846E+02   0.6563E+01   0.3030E+00
 15    7    11   0.6247E+01   0.6846E+02   0.6563E+01   0.3030E+00
 16    7    12   0.6247E+01   0.6846E+02   0.6563E+01   0.3030E+00
 17    1     5   0.6247E+01   0.1196E+03   0.6563E+01   0.3030E+00
 18    2     5   0.6247E+01   0.1196E+03   0.6563E+01   0.3030E+00
 19    5     9   0.6247E+01   0.1097E+03   0.6563E+01   0.3030E+00
 20    5    10   0.6247E+01   0.1097E+03   0.6563E+01   0.3030E+00
 21    9    12   0.6247E+01   0.2172E+03   0.6563E+01   0.3030E+00
 22   10    11   0.6247E+01   0.2172E+03   0.6563E+01   0.3030E+00
 23   11    12   0.6247E+01   0.8400E+02   0.6563E+01   0.3030E+00
 24    9    10   0.6247E+01   0.1894E+03   0.6563E+01   0.3030E+00
 25   12    21   0.5979E+02   0.1081E+03   0.1900E+02   0.1002E+01
 26   11    18   0.5979E+02   0.1081E+03   0.1900E+02   0.1002E+01
 27    9    16   0.5979E+02   0.1111E+03   0.1900E+02   0.1002E+01
 28   10    17   0.5979E+02   0.1111E+03   0.1900E+02   0.1002E+01
 29    9    21   0.7358E+01   0.2380E+03   0.7767E+01   0.3016E+00
 30   10    18   0.7358E+01   0.2380E+03   0.7767E+01   0.3016E+00
 31   11    13   0.7358E+01   0.6846E+02   0.7767E+01   0.3016E+00
 32   12    13   0.7358E+01   0.6846E+02   0.7767E+01   0.3016E+00
```

```
 33     13      18   0.7358E+01   0.6846E+02   0.7767E+01   0.3016E+00
 34     13      21   0.7358E+01   0.6846E+02   0.7767E+01   0.3016E+00
 35     10      16   0.7358E+01   0.2094E+03   0.7767E+01   0.3016E+00
 36     16      21   0.5424E+01   0.1866E+03   0.5024E+01   0.3437E+00
 37     17      18   0.5424E+01   0.1866E+03   0.5024E+01   0.3437E+00
 38     18      21   0.5424E+01   0.8400E+02   0.5024E+01   0.3437E+00
 39     16      17   0.5424E+01   0.1663E+03   0.5024E+01   0.3437E+00
 40     12      20   0.5424E+01   0.1232E+03   0.5024E+01   0.3437E+00
 41     11      19   0.5424E+01   0.1232E+03   0.5024E+01   0.3437E+00
 42     20      21   0.5424E+01   0.6456E+02   0.5024E+01   0.3437E+00
 43     18      19   0.5424E+01   0.6456E+02   0.5024E+01   0.3437E+00
 44     19      20   0.5424E+01   0.8400E+02   0.5024E+01   0.3437E+00
 45     21      29   0.5979E+02   0.1081E+03   0.1900E+02   0.1002E+01
 46     18      28   0.5979E+02   0.1081E+03   0.1900E+02   0.1002E+01
 47     16      26   0.5979E+02   0.1112E+03   0.1900E+02   0.1002E+01
 48     17      27   0.5979E+02   0.1112E+03   0.1900E+02   0.1002E+01
 49     16      29   0.1098E+02   0.2112E+03   0.9952E+01   0.3511E+00
 50     17      28   0.1098E+02   0.2112E+03   0.9952E+01   0.3511E+00
 51     20      32   0.5424E+01   0.1209E+03   0.5024E+01   0.3437E+00
 52     19      30   0.5424E+01   0.1209E+03   0.5024E+01   0.3437E+00
 53     20      31   0.1098E+02   0.1626E+03   0.9952E+01   0.3511E+00
 54     19      31   0.1098E+02   0.1626E+03   0.9952E+01   0.3511E+00
 55     18      24   0.1098E+02   0.6846E+02   0.9952E+01   0.3511E+00
 56     21      24   0.1098E+02   0.6846E+02   0.9952E+01   0.3511E+00
 57     24      28   0.1098E+02   0.6846E+02   0.9952E+01   0.3511E+00
 58     24      29   0.1098E+02   0.6846E+02   0.9952E+01   0.3511E+00
 59     16      25   0.1098E+02   0.1384E+03   0.9952E+01   0.3511E+00
 60     17      25   0.1098E+02   0.1384E+03   0.9952E+01   0.3511E+00
 61     26      29   0.1648E+02   0.1558E+03   0.1082E+02   0.4848E+00
 62     27      28   0.1648E+02   0.1558E+03   0.1082E+02   0.4848E+00
 63     29      32   0.1648E+02   0.1240E+03   0.1082E+02   0.4848E+00
 64     28      30   0.1648E+02   0.1240E+03   0.1082E+02   0.4848E+00
 65     31      32   0.1648E+02   0.7684E+02   0.1082E+02   0.4848E+00
 66     30      31   0.1648E+02   0.7684E+02   0.1082E+02   0.4848E+00
 67     28      29   0.1648E+02   0.8400E+02   0.1082E+02   0.4848E+00
 68     15      60   0.3142E-06   0.1000E+00   0.0          0.0
 69     15      60   0.3142E-06   0.1000E+00   0.0          0.0
 70     30      32   0.1648E+02   0.9600E+02   0.1082E+02   0.4848E+00
 71     29      39   0.5979E+02   0.9611E+02   0.1900E+02   0.1002E+01
 72     28      37   0.5979E+02   0.9611E+02   0.1900E+02   0.1002E+01
 73     26      34   0.5979E+02   0.9879E+02   0.1900E+02   0.1002E+01
 74     27      36   0.5979E+02   0.9879E+02   0.1900E+02   0.1002E+01
 75     26      39   0.1667E+02   0.1792E+03   0.1056E+02   0.5026E+00
 76     27      37   0.1667E+02   0.1792E+03   0.1056E+02   0.5026E+00
 77     29      40   0.1667E+02   0.1000E+03   0.1056E+02   0.5026E+00
 78     28      38   0.1667E+02   0.1000E+03   0.1056E+02   0.5026E+00
 79     26      52   0.1667E+02   0.2066E+03   0.1056E+02   0.5026E+00
 80     27      53   0.1667E+02   0.2066E+03   0.1056E+02   0.5026E+00
 81     28      33   0.1667E+02   0.6382E+02   0.1056E+02   0.5026E+00
 82     29      33   0.1667E+02   0.6382E+02   0.1056E+02   0.5026E+00
 83     33      37   0.1667E+02   0.6382E+02   0.1056E+02   0.5026E+00
 84     33      39   0.1667E+02   0.6382E+02   0.1056E+02   0.5026E+00
 85     34      39   0.1667E+02   0.1289E+03   0.1056E+02   0.5026E+00
 86     36      37   0.1667E+02   0.1289E+03   0.1056E+02   0.5026E+00
 87     39      40   0.1667E+02   0.3254E+02   0.1056E+02   0.5026E+00
 88     37      38   0.1667E+02   0.3254E+02   0.1056E+02   0.5026E+00
 89     39      47   0.5979E+02   0.7209E+02   0.1900E+02   0.1002E+01
 90     37      45   0.5979E+02   0.7209E+02   0.1900E+02   0.1002E+01
 91     34      42   0.5979E+02   0.7411E+02   0.1900E+02   0.1002E+01
 92     36      43   0.5979E+02   0.7411E+02   0.1900E+02   0.1002E+01
 93     34      47   0.1697E+02   0.1446E+03   0.1035E+02   0.5219E+00
 94     36      45   0.1697E+02   0.1446E+03   0.1035E+02   0.5219E+00
 95     40      48   0.1667E+02   0.7428E+02   0.1056E+02   0.5026E+00
 96     38      46   0.1667E+02   0.7428E+02   0.1056E+02   0.5026E+00
 97     25      26   0.1667E+02   0.7176E+02   0.1056E+02   0.5026E+00
 98     25      27   0.1667E+02   0.7176E+02   0.1056E+02   0.5026E+00
 99     26      35   0.1667E+02   0.1217E+03   0.1056E+02   0.5026E+00
100     27      35   0.1667E+02   0.1217E+03   0.1056E+02   0.5026E+00
101     34      35   0.1667E+02   0.6168E+02   0.1056E+02   0.5026E+00
102     35      36   0.1667E+02   0.6168E+02   0.1056E+02   0.5026E+00
103     35      42   0.1667E+02   0.9138E+02   0.1056E+02   0.5026E+00
104     35      43   0.1667E+02   0.9138E+02   0.1056E+02   0.5026E+00
```

VII. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

An existing finite element code was expanded to encompass the more general case of frame members; i.e., six degrees of freedom per joint. Combined truss and frame structures were designed for minimum weight with multiple load conditions considered.

The displacement method was used for static analysis and the subspace iteration method was used for eigenvalues.

Several examples were considered. In every case the code worked as an analysis tool, and significant weight reductions were obtained with the coupled optimizer CONMIN.

The SADX design code has been shown to be a useful tool for ship mast optimum design.

B. RECOMMENDATIONS

The following recommendations may be of value for future work.

1. The routines necessary to calculate gradients analytically should be added to the code.

2. The code should be extended to include plate and shear elements and a library of member cross-sections.

3. An out of core equation solver should be added.

4. The ability to specify multipliers for applying inertial loads along the three coordinate axes should be added in a fashion similar to that used for applying structure's own weight as loads. Such an addition would simplify dynamic load analysis and design.

5. The method of gradient calculation should be dependent on specific gradients required [Ref. 7] and [Ref. 8].

6. Gradients of frequency constraints would benefit from a more efficient algorithm [Ref. 9].

7. The need for a large scale public structural optimization code still exists.

8. The code should be modified to allow optimum member size design followed by simultaneous optimum member size and optimum geometry design.

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APPENDIX A

DATA FILES

A. INTRODUCTION

This appendix contains the data files used to create the test cases in Chapter VI. Additionally the data file for the USER'S guide in complete form is presented.

TABLE X

DATA FILE TRUSS-BRACED CANTILEVER BEAM

```
$********1*********2*********3*********4*********5*********6*********7**********
$BLOCK A TITLE                         1 CARD    FORMAT  80H
TRUSS-BRACED CANTILEVER BEAM: EXAMPLE 1
$********1*********2*********3*********4*********5*********6*********7**********
$BLOCK B CONTROL PARAMETERS            3 CARDS   FORMAT  8I10
$  NEB       NEF        NJ       NCJ       NMT     IOVCLC      NOJ
$        |         |         |         |         |         |         |
         2         2         5         3         2         2         2
$ NEUBC     LBLCK     NFREQ    NFMASS     NEIG      NEIG1     NPRI
$        |         |         |         |         |         |         |
         1         1         1         1         1         2         0
$  NLC     NOSPLC     NSTRES    NSTW      NFMW
$        |         |         |         |         |
         2         2         2         1         1
$********1*********2*********3*********4*********5*********6*********7**********
$BLOCK C DYNAMIC ANALYSIS INFORMATION  1 CARD    FORMAT  I10,2F10.0
$ LMASS     GRAV     EPSEIG
$        |         |         |
         0     386.4        0.
$********1*********2*********3*********4*********5*********6*********7**********
$BLOCK D JOINT COORDINATES
$    NJ CARDS                                    FORMAT I10,3F10
$   JN      X-COORD   Y-COORD   Z-COORD
$        |         |         |         |
         1        0.        0.        0.
         2      100.        0.        0.
         3      200.        0.        0.
         4        0.      150.        0.
         5        0.        0.       50.
$BLOCK E DESIGN VARIABLE LINKING DATA
$    NOJ CARDS                                   FORMAT 4I10,3F10.0
$   JN       IX        IY        IZ       PCX       PCY       PCZ
$        |         |         |         |         |         |         |
         4         0         1         0       1.0       1.0       1.0
         5         0         0         2       1.0       1.0       1.0
$********1*********2*********3*********4*********5*********6*********7**********
$BLOCK F MATERIAL PROPERTIES         NMT CARDS   FORMAT  6F10.0
$    E       RFC      SIGMIN    SIGMAX   KEULER    POISSN
$        |         |         |         |         |         |
    1.0E+7       0.1    -25000.     25000.        2.       .27
    2.9E+7       0.3    -36000.     36000.        2.       .27
$********1*********2*********3*********4*********5*********6*********7**********
$BLOCK G BAR ELEMENT INFORMATION     NEB CARDS   FORMAT  5I10,F10,I10
$   LNO     NODE2     NODE3    MATCOD     NSDG1     AREA      LSECT
$        |         |         |         |         |         |         |
         1         2         4         1         1       3.0         1
         2         2         5         1         2       3.0         1
$********1*********2*********3*********4*********5*********6*********7**********
$BLOCK H FRAME ELEMENT INFORMATION       2*NEF CARDS FORMAT 7I10/2F10
$   LNO     NODE2     NODE3    MATCOD     NSDG1     NSDG2     LSECT
$        |         |         |         |         |         |         |
         3         1         2         2         3         4         1
$CHARDIM1  CHARDIM2
$        |         |
       5.0       1.0
         4         2         3         2         3         5         1
       5.0       1.0
$********1*********2*********3*********4*********5*********6*********7**********
$BLOCK I JOINT CONSTRAINT DATA       NCJ CARDS   FORMAT  7I10
$  JN        IX        IY        IZ        IXX       IYY       IZZ
$        |         |         |         |         |         |         |
         1         1         1         1         1         1         1
         2         0         0         0         0         0         0
         3         0         0         0         0         0         0
         4         1         1         1         1         1         1
         5         1         1         1         1         1         1
$********1*********2*********3*********4*********5*********6*********7**********
$BLOCK J JOINT LOADING DATA            1 CARD    FORMAT I10
$     (OMIT IF NLC=0 IN BLOCK B)
$  NLJ
$        |
         1
```

TABLE XI

DATA FILE TRUSS-BRACED CANTILEVER BEAM continued

```
$                                    NLJ CARDS   FORMATI10,6F10
$   JN        FX        FY        FZ        TX        TY        TZ
$        |         |         |         |         |         |         |
         3        0.    1000.0        0.        0.        0.        0.
         1
         3        0.       0.0   -1000.0        0.        0.        0.
$********1*********2*********3*********4*********5*********6*********7**********
$BLOCK K FIXED MASS DATA         NFMASS CARDS   FORMAT I10,F10.0
$     (OMIT IF NFMASS=0 IN BLOCK B)
$   JN      MASS
$        |         |
         3     250.0
$********1*********2*********3*********4*********5*********6*********7**********
$BLOCK L DESIGN VARIABLE INFORMATION  CARDS AS REQ'D    FORMAT 8F10.0
$   (AREA AND DIMENSION VARIABLES      OMIT IF NDVAR1=0)
$    XA(I) .  .  .  XA(NDVAR1)
$        |         |         |         |         |         |         |
      20.0      20.0      20.0       2.0       2.0
$   XAL(I)
$        |         |         |         |         |         |         |
       .50       .50       4.0       .10       .10
$   XAU(I)
$        |         |         |         |         |         |         |
      25.0      35.0      25.0       2.5       4.0
$********1*********2*********3*********4*********5*********6*********7**********
$BLOCK M DESIGN VARIABLE INFORMATION  CARDS AS REQ'D    FORMAT 8F10.0
$     (COORDINATE VARIABLES            OMIT IF NDVAR2=0)
$    XC(I) .  .  .  XC(NDVAR2)
$        |         |         |         |         |         |         |
     150.0      50.0
$   XCL(I)
$        |         |         |         |         |         |         |
       0.0       0.0
$   XCU(I)
$        |         |         |         |         |         |         |
     200.0     100.0
$********1*********2*********3*********4*********5*********6*********7**********
$BLOCK N JOINT DISPLACEMENT CONSTRAINTS   NDSPLC CARDS   FORMAT 3I10,2F10
$     (OMIT IF NDSPLC=0 IN BLOCK B)
$   JN       DIR       LC         BL         BU
$        |         |         |         |         |
         3         2         1      -3.0       3.0
         3         3         2      -3.5       3.5
$********1*********2*********3*********4*********5*********6*********7**********
$BLOCK O FREQUENCY CONSTRAINTS    NO. OF CARDS AS REQ'D      FORMAT 8F10.0
$     (OMIT IF NFREQ=0 IN BLOCK B)
$      FC1  .  . FCN
$        |         |         |         |         |         |         |
       1.0
$********1*********2*********3*********4*********5*********6*********7**********
$BLOCK P END CARD
END
```

TABLE XII

DATA FILE TWO-TIER 3-D PORTAL FRAME

```
$*********1*********2*********3*********4*********5*********6*********7*********
$BLOCK A TITLE                          1 CARD    FORMAT  80H
 2-TIER FRAME STRUCTURE WITH TRUSS X-BRACES: EXAMPLE 2
$*********1*********2*********3*********4*********5*********6*********7*********
$BLOCK B CONTROL PARAMETERS             3 CARDS   FORMAT  8I10
$  NEB       NEF        NJ       NCJ       NMT     IDVCLC       NDJ
$        |         |         |         |         |         |         |
        20        16        12         8         1         2         8
$ NEUBC     LBLCK     NFREQ    NFMASS      NEIG     NEIG1      NPRI
$        |         |         |         |         |         |         |
         1         1         1         4         3         6         0
$  NLC     NDSFLC     NSTRES    NSTW       NFMW
$        |         |         |         |         |
         3        12         2         1         1
$*********1*********2*********3*********4*********5*********6*********7*********
$BLOCK C DYNAMIC ANALYSIS INFORMATION   1 CARD    FORMAT  I10,2F10.0
$ LMASS      GRAV    EPSEIG
$        |         |         |
         0     386.4        0.
$*********1*********2*********3*********4*********5*********6*********7*********
$BLOCK D JOINT COORDINATES
$    NJ CARDS                                     FORMAT I10,3F10
$   JN     X-COORD   Y-COORD   Z-COORD
$        |         |         |         |
         1      100.        0.      100.
         2      100.        0.     -100.
         3     -100.        0.     -100.
         4     -100.        0.      100.
         5      100.       50.      100.
         6      100.       50.     -100.
         7     -100.       50.     -100.
         8     -100.       50.      100.
         9      100.      100.      100.
        10      100.      100.     -100.
        11     -100.      100.     -100.
        12     -100.      100.      100.
$*********1*********2*********3*********4*********5*********6*********7*********
$BLOCK E DESIGN VARIABLE LINKING DATA
$    NDJ CARDS                                    FORMAT 4I10,3F10.0
$   JN       IX        IY        IZ        PCX       PCY       PCZ
$        |         |         |         |         |         |         |
         1         1         0         2       1.0       0.0       1.0
         2         1         0         2       1.0       0.0      -1.0
         3         1         0         2      -1.0       0.0      -1.0
         4         1         0         2      -1.0       0.0       1.0
         5         3         4         5       1.0       1.0       1.0
         6         3         4         5       1.0       1.0      -1.0
         7         3         4         5      -1.0       1.0      -1.0
         8         3         4         5      -1.0       1.0       1.0
$*********1*********2*********3*********4*********5*********6*********7*********
$BLOCK F MATERIAL PROPERTIES          NMT CARDS   FORMAT  6F10.0
$    E       RHO      SIGMIN    SIGMAX   KEULER    POISSN
$        |         |         |         |         |         |
    2.9E+7       0.3   -42000.    36000.        4.       .27
$*********1*********2*********3*********4*********5*********6*********7*********
$BLOCK G BAR ELEMENT INFORMATION      NEB CARDS   FORMAT  5I10,F10,I10
$   LNG     NODE2     NODE3     MATCOD     NSDG1     AREA      LSECT
$        |         |         |         |         |         |
         1         1         6         1         1       5.0         1
2,5,2,1,1,5.0,1
3,2,7,1,1,5.0,1
4,6,3,1,1,5.0,1
5,3,8,1,1,5.0,1
6,7,4,1,1,5.0,1
7,4,5,1,1,5.0,1
8,1,8,1,1,5.0,1
9,5,7,1,1,5.0,1
10,6,8,1,1,5.0,1
11,5,10,1,2,5.0,1
12,6,9,1,2,5.0,1
13,6,11,1,2,5.0,1
14,7,10,1,2,5.0,1
```

TABLE XIII

DATA FILE TWO-TIER 3-D PORTAL FRAME continued

```
15,7,12,1,2,5.0,1
16,8,11,1,2,5.0,1
17,8,9,1,2,5.0,1
18,5,12,1,2,5.0,1
19,9,11,1,2,5.0,1
20,10,12,1,2,5.0,1
$********1*********2*********3*********4*********5*********6*********7**********
$BLOCK H FRAME ELEMENT INFORMATION       2*NEF CARDS FORMAT 7I10/2F10
$   LNO     NODE2     NODE3    MATCOD     NSDG1     NSDG2     LSECT
$        |         |         |         |         |         |         |
21,1,5,1,3,4,1
       5.0      0.50
22,2,6,1,3,4,1
       5.0      0.50
23,3,7,1,3,4,1
       5.0      0.50
24,4,8,1,3,4,1
       5.0      0.50
25,5,9,1,5,6,1
       5.0      0.50
26,6,10,1,5,6,1
       5.0      0.50
27,7,11,1,5,6,1
       5.0      0.50
28,8,12,1,5,6,1
       5.0      0.50
29,5,6,1,7,8,1
       5.0      0.50
30,6,7,1,7,8,1
       5.0      0.50
31,7,8,1,7,8,1
       5.0      0.50
32,8,5,1,7,8,1
       5.0      0.50
33,9,10,1,9,10,1
       5.0      0.50
34,10,11,1,9,10,1
       5.0      0.50
35,11,12,1,9,10,1
       5.0      0.50
36,12,9,1,9,10,1
       5.0      0.50
$********1*********2*********3*********4*********5*********6*********7**********
$BLOCK I JOINT CONSTRAINT DATA          NCJ CARDS    FORMAT   7I10
$  JN         IX        IY        IZ        IXX        IYY        IZZ
$        |         |         |         |         |         |         |
1,1,1,1,1,1,1
2,1,1,1,1,1,1
3,1,1,1,1,1,1
4,1,1,1,1,1,1
5,
6,
7,
8,
9,
10,
11,
12,
$********1*********2*********3*********4*********5*********6*********7**********
$BLOCK J JOINT LOADING DATA             1 CARD     FORMAT I10
$     (OMIT IF NLC=0 IN BLOCK B)
$  NLJ
$        |
2,
$                                       NLJ CARDS    FORMAT  I10,6F10
$   JN        FX        FY        FZ        TX        TY        TZ
$        |         |         |         |         |         |         |
9,1000.
10,1000.
4,
9,500.
10,500.
```

TABLE XIV

DATA FILE TWO-TIER 3-D PORTAL FRAME continued

```
5,-500.
6,-500.
4,
10,1000.
9,0.0,0.0,1000.
12,-1000.
11,0.0,0.0,-1000.
$*********1*********2*********3*********4*********5*********6*********7*********
$BLOCK K FIXED MASS DATA         NFMASS CARDS   FORMAT I10,F10.0
$      (OMIT IF NFMASS=0 IN BLOCK B)
$    JN        MASS
$        |         |
9,50.0
10,50.0
11,50.0
12,50.0
$*********1*********2*********3*********4*********5*********6*********7*********
$BLOCK L DESIGN VARIABLE INFORMATION  CARDS AS REQ'D     FORMAT 8F10.0
$     (AREA AND DIMENSION VARIABLES        OMIT IF NDVAR1=0)
$     XA(I) .  .  .  XA(NDVAR1)
$        |         |         |         |         |         |         |
       3.5       3.5       5.0       0.5       5.0       0.5       5.0       0.5
       5.0       0.5
$    XAL(I)
$        |         |         |         |         |         |         |
       0.1       0.1       .50       0.1       .50       0.1       .50       0.1
       .50       0.1
$    XAU(I)
$        |         |         |         |         |         |         |
      30.0      30.0      30.0       .50      30.0       .50      30.0       0.5
      30.0       .50
$*********1*********2*********3*********4*********5*********6*********7*********
$BLOCK M DESIGN VARIABLE INFORMATION  CARDS AS REQ'D     FORMAT 8F10.0
$     (COORDINATE VARIABLES               OMIT IF NDVAR2=0)
$     XC(I) .  .  .  XC(NDVAR2)
$        |         |         |         |         |         |         |
     100.0     100.0     100.0     100.0      50.0
$    XCL(I)
$        |         |         |         |         |         |         |
      20.0      20.0      20.0      20.0      20.0
$    XCU(I)
$        |         |         |         |         |         |         |
     160.0     160.0     160.0     160.0      80.0
$*********1*********2*********3*********4*********5*********6*********7*********
$BLOCK N JOINT DISPLACEMENT CONSTRAINTS    NDSPLC CARDS   FORMAT 3I10,2F10
$      (OMIT IF NDSPLC=0 IN BLOCK B)
$    JN        DIR       LC          BL        BU
$        |         |         |         |         |
         9         1         1      -5.0       5.0
        10         1         1      -5.0       5.0
        11         1         1      -5.0       5.0
        12         1         1      -5.0       5.0
         9         1         2      -5.0       5.0
        10         1         2      -5.0       5.0
        11         1         2      -5.0       5.0
        12         1         2      -5.0       5.0
         9         3         3      -5.0       5.0
        10         1         3      -5.0       5.0
        11         3         3      -5.0       5.0
        12         1         3      -5.0       5.0
$*********1*********2*********3*********4*********5*********6*********7*********
$BLOCK O FREQUENCY CONSTRAINTS     NO. OF CARDS AS REQ'D     FORMAT 8F10.0
$      (OMIT IF NFREQ=0 IN BLOCK B)
$       FC1  .  . FCN
$        |         |         |         |         |         |         |
       1.0       5.0      10.0
$*********1*********2*********3*********4*********5*********6*********7*********
$BLOCK P END CARD
END
```

TABLE XV

DATA FILE DD-963 FOREMAST

```
$BLOCK A TITLE
DD-963 CLASS DESTROYER FORWARD MAST REDESIGN: EXAMPLE 1
$   THIS IS A SIMPLIFICATION  OF THE ACTUAL STRUCTURE AND LOADS BASED ON
$   NAVSHIPS DRAWING NUMBER 128-4539510 AND NAVSHIPS SKETCH NUMBER
$   80064-128-SK4587979
$   THIS ANALYSIS REQUIRES A THE X-AXIS FORWARD, Y-AXIS UP, AND Z-AXIS
$   TO STBD; A DIFFERENT ORIENTATION THAN IN THE ABOVE DRAWINGS
$BLOCK B CONTROL PARAMETERS
$  NEB       NEF        NJ       NCJ       NMT     IDVCLC     NDJ
$        |         |         |         |         |         |         |
         0       172        73        20         1         1         0
$ NEUBC     LBLCK     NFREQ    NFMASS     NEIG      NEIG1    NPRI
$        |         |         |         |         |         |         |
         1         1         0        33         0         0         0
$  NLC     NDSFLC     NSTRES    NSTW      NFMW
$        |         |         |         |         |
         1        11         2         1         1
$********1*********2*********3*********4*********5*********6*********7***
$BLOCK C DYNAMIC ANALYSIS INFORMATION
         0     386.4        0.
$BLOCK D JOINT COORDINATES
         1    -240.0       0.0    -106.0
         2    -240.0       0.0     106.0
         3       0.0       0.0      42.0
         4       0.0       0.0     -42.0
         5    -228.0      54.0       0.0
         6    -120.0      54.0      68.4
         7     -2.64      54.0       0.0
         8    -120.0      54.0     -68.4
         9    -216.0     108.0     -94.7
        10    -216.0     108.0      94.7
        11     -5.28     108.0      42.0
        12     -5.28     108.0     -42.0
        13     -7.92     162.0       0.0
        14    -172.0     444.0       0.0
$ NODE 15 IS AN UNCONNECTED FIXED DUMMY NODE
        15       0.1       0.0       0.0
        16    -192.6     216.0    -83.16
        17    -192.6     216.0     83.16
        18    -10.56     216.0      42.0
        19      54.0     216.0      42.0
        20      54.0     216.0     -42.0
        21    -10.56     216.0     -42.0
        22    -172.0     736.0     -18.0
        23    -172.0     736.0      18.0
        24     -13.2     270.0       0.0
        25    -168.8     324.0       0.0
        26    -168.8     324.0    -71.76
        27    -168.8     324.0     71.76
        28    -15.84     324.0      42.0
        29    -15.84     324.0     -42.0
        30     108.0     324.0      48.0
        31     168.0     324.0       0.0
        32     108.0     324.0     -48.0
        33    -18.12     372.0       0.0
        34    -147.8     420.0    -61.68
        35    -147.8     420.0       0.0
        36    -147.8     420.0     61.68
        37     -20.4     420.0      42.0
        38      12.0     420.0      39.0
        39     -20.4     420.0     -42.0
        40      12.0     420.0     -39.0
        41     -22.2     456.0       0.0
        42    -132.0     492.0     -54.0
        43    -132.0     492.0      54.0
        44    -172.0     492.0     -54.0
        45     -24.0     492.0      42.0
        46      30.0     492.0      36.0
        47     -24.0     492.0     -42.0
        48      30.0     492.0     -36.0
$ END NODES FOR THE LOWER QUADRAPOD OF THE FORWARD MAST
$ START THE UPPER FOREMAST NODES
```

TABLE XVI

DATA FILE DD-963 FOREMAST continued

```
        49     -172.0      492.0     -120.0
        50     -172.0      492.0      120.0
        51     -228.0      408.0        0.0
        52     -288.0      492.0      -56.0
        53     -288.0      492.0       56.0
        54     -240.0      492.0        0.0
        55     -172.0      492.0     -276.0
        56     -172.0      492.0      276.0
        57     -218.0      600.0      -24.0
        58     -218.0      600.0       24.0
        59     -172.0      492.0       54.0
$ NODE 60 IS AN UNCONNECTED FIXED DUMMY NODE
        60        0.0        0.0        0.0
        61     -172.0      600.0        0.0
        62     -172.0      492.0        0.0
        63     -172.0      664.0        0.0
        64     -172.0      736.0        0.0
        65     -172.0      896.0        0.0
        66     -172.0      976.0        0.0
        67     -172.0     1056.0        0.0
        68     -172.0      736.0     -264.0
        69     -172.0      736.0      264.0
        70     -172.0      736.0     -156.0
        71     -172.0      736.0      156.0
        72     -172.0      736.0     -228.0
        73     -172.0      736.0      228.0
$*********1*********2*********3*********4*********5*********6*********7***
$BLOCK F MATERIAL INFORMATION
   2.9E+7        0.1    -42000.     42000.         4.        .27
$*********1*********2*********3*********4*********5*********6*********7***
$BLOCK G BAR ELEMENT INFORMATION      NEB CARDS    FORMAT   5I10,F10,I10
$    LNC      NODE2     NODE3     MATCOD     NSDG1      AREA      LSECT
$        |         |         |         |         |         |         |
$*********1*********2*********3*********4*********5*********6*********7***
$BLOCK H FRAME ELEMENT INFORMATION
$ START FRAME ELEMENTS FOR 1ST OR LOWEST TIER OF QUADRAPOD
         1         4        12         1         1         2         1
     11.75       .75
         2         3        11         1         1         2         1
     11.75       .75
         3         1         9         1         1         2         1
     11.75       .75
         4         2        10         1         1         2         1
     11.75       .75
         5         4         8         1         3         4         1
     7.625      .375
         6         3         6         1         3         4         1
     7.625      .375
         7         1         8         1         3         4         1
     7.625      .375
         8         2         6         1         3         4         1
     7.625      .375
         9         8        12         1         3         4         1
     7.625      .375
        10         6        11         1         3         4         1
     7.625      .375
        11         8         9         1         3         4         1
     7.625      .375
        12         6        10         1         3         4         1
     7.625      .375
        13         3         7         1         3         4         1
     7.625      .375
        14         4         7         1         3         4         1
     7.625      .375
        15         7        11         1         3         4         1
     7.625      .375
        16         7        12         1         3         4         1
     7.625      .375
        17         1         5         1         3         4         1
     7.625      .375
        18         2         5         1         3         4         1
     7.625      .375
```

TABLE XVII

DATA FILE DD-963 FOREMAST continued

```
        19          5          9       1       3       4       1
     7.625       .375
        20          5         10       1       3       4       1
     7.625       .375
        21         12          9       1       3       4       1
     7.625       .375
        22         11         10       1       3       4       1
     7.625       .375
        23         11         12       1       3       4       1
     7.625       .375
        24          9         10       1       3       4       1
     7.625       .375
$ END 1ST TIER OF QUADRAPOD START 2ND TIER
        25         12         21       1       1       2       1
     11.75        .75
        26         11         18       1       1       2       1
     11.75        .75
        27          9         16       1       1       2       1
     11.75        .75
        28         10         17       1       1       2       1
     11.75        .75
        29          9         21       1       5       6       1
     7.625       .375
        30         10         18       1       5       6       1
     7.625       .375
        31         11         13       1       5       6       1
     7.625       .375
        32         12         13       1       5       6       1
     7.625       .375
        33         13         18       1       5       6       1
     7.625       .375
        34         13         21       1       5       6       1
     7.625       .375
        35         10         16       1       5       6       1
     7.625       .375
        36         21         16       1       7       8       1
     7.625       .375
        37         17         18       1       7       8       1
     7.625       .375
        38         18         21       1       7       8       1
     7.625       .375
        39         16         17       1       7       8       1
     7.625       .375
        40         12         20       1       7       8       1
    11.625       .375
        41         11         19       1       7       8       1
    11.625       .375
        42         20         21       1       7       8       1
     7.625       .375
        43         18         19       1       7       8       1
     7.625       .375
        44         19         20       1       7       8       1
     7.625       .375
$ END THE 2ND TIER OF THE QUADRAPOD START THE 3RD TIER
        45         21         29       1       1       2       1
     11.75        .75
        46         18         28       1       1       2       1
     11.75        .75
        47         16         26       1       1       2       1
     11.75        .75
        48         17         27       1       1       2       1
     11.75        .75
        49         16         29       1       9      10       1
     7.625       .375
        50         17         28       1       9      10       1
     7.625       .375
        51         20         32       1       7       8       1
    11.625       .375
        52         19         30       1       7       8       1
    11.625       .375
        53         20         31       1       9      10       1
     7.625       .375
```

TABLE XVIII

DATA FILE DD-963 FOREMAST continued

```
       54        19          31          1          9         10          1
    7.625      .375
       55        18          24          1          9         10          1
    7.625      .375
       56        21          24          1          9         10          1
    7.625      .375
       57        24          28          1          9         10          1
    7.625      .375
       58        24          29          1          9         10          1
    7.625      .375
       59        16          25          1          9         10          1
    11.50       .50
       60        17          25          1          9         10          1
    11.50       .50
$ MEMBERS 61 THRU 70 MODEL THE SPQ-9 PLATFORM ALONG WITH A FIXED MASS
       61        26          29          1         11         12          1
    11.50       .50
       62        27          28          1         11         12          1
    11.50       .50
       63        29          32          1         11         12          1
    11.50       .50
       64        28          30          1         11         12          1
    11.50       .50
       65        31          32          1         11         12          1
    11.50       .50
       66        31          30          1         11         12          1
    11.50       .50
       67        28          29          1         11         12          1
    11.50       .50
$ ELEMENTS 68 AND 69 ARE DUMMY ELEMENTS
       68        15          60          1          0          0          1
     .001     .0001
       69        15          60          1          0          0          1
     .001     .0001
       70        30          32          1         11         12          1
    11.50       .50
$ END THE 3RD TIER OF THE QUADRAPOD START THE 4TH TIER
       71        29          39          1          1          2          1
    11.75       .75
       72        28          37          1          1          2          1
    11.75       .75
       73        26          34          1          1          2          1
    11.75       .75
       74        27          36          1          1          2          1
    11.75       .75
       75        26          39          1         13         14          1
    7.625      .375
       76        27          37          1         13         14          1
    7.625      .375
       77        29          40          1         13         14          1
    7.625      .375
       78        28          38          1         13         14          1
    7.625      .375
       79        26          52          1         13         14          1
    7.625      .375
       80        27          53          1         13         14          1
    7.625      .375
       81        28          33          1         13         14          1
    7.625      .375
       82        29          33          1         13         14          1
    7.625      .375
       83        33          37          1         13         14          1
    7.625      .375
       84        33          39          1         13         14          1
    7.625      .375
       85        34          39          1         13         14          1
    7.625      .375
       86        36          37          1         13         14          1
    7.625      .375
       87        39          40          1         13         14          1
    7.625      .375
       88        37          38          1         13         14          1
```

TABLE XIX

DATA FILE DD-963 FOREMAST continued

```
     7.625       .375
      124          53        54       1       15       16       1
     7.625       .375
      125          42        54       1       15       16       1
     7.625       .375
      126          43        54       1       15       16       1
     7.625       .375
      127          42        44       1       15       16       1
     7.625       .375
      128          43        59       1       15       16       1
     7.625       .375
$ END THE LOWER QUADRAPOD START THE TOPMAST MEMBERS
      129          52        58       1       17       18       1
     7.625       .375
      130          52        57       1       17       18       1
     7.625       .375
      131          53        58       1       17       18       1
     7.625       .375
      132          57        61       1       17       18       1
     7.625       .375
      133          58        61       1       17       18       1
     7.625       .375
      134          57        58       1       17       18       1
     7.625       .375
      135          57        63       1       17       18       1
     7.625       .375
      136          58        63       1       17       18       1
     7.625       .375
      137          14        25       1       19       20       1
     23.00        1.5
      138          14        62       1       19       20       1
     23.00        1.5
      139          62        61       1       19       20       1
     23.00        1.5
      140          61        63       1       19       20       1
     23.00        1.5
      141          63        64       1       19       20       1
     23.00        1.5
      142          64        65       1       21       22       1
      9.50        .50
      143          65        66       1       21       22       1
      9.50        .50
      144          66        67       1       21       22       1
      9.50        .50
      145          37        39       1       13       14       1
     7.625       .375
$ UPPER YARDARMS AND BRACES
      146          64        70       1       23       24       1
     14.00        .75
      147          64        71       1       23       24       1
     14.00        .75
      148          70        72       1       25       26       1
     10.00        .50
      149          71        73       1       25       26       1
     10.00        .50
      150          72        68       1       25       26       1
     10.00        .50
      151          73        69       1       25       26       1
     10.00        .50
      152          61        72       1       27       28       1
     7.625       .375
      153          61        73       1       27       28       1
     7.625       .375
      154          63        70       1       29       30       1
      5.75        .25
      155          63        71       1       29       30       1
      5.75        .25
      156          61        72       1       27       28       1
     7.625       .375
      157          61        73       1       27       28       1
     7.625       .375
      158          63        70       1       29       30       1
```

TABLE XX

DATA FILE DD-963 FOREMAST continued

```
      7.625       .375
$ END THE 4RD TIER OF THE CUADRAPOD START THE 5TH TIER
         89         39         47          1          1          2          1
      11.75        .75
         90         37         45          1          1          2          1
      11.75        .75
         91         34         42          1          1          2          1
      11.75        .75
         92         36         43          1          1          2          1
      11.75        .75
         93         34         47          1         15         16          1
      7.625       .375
         94         36         45          1         15         16          1
      7.625       .375
         95         40         48          1         13         14          1
      7.625       .375
         96         38         46          1         13         14          1
      7.625       .375
         97         25         26          1         13         14          1
      7.625       .375
         98         25         27          1         13         14          1
      7.625       .375
         99         26         35          1         13         14          1
      7.625       .375
        100         27         35          1         13         14          1
      7.625       .375
        101         34         35          1         13         14          1
      7.625       .375
        102         35         36          1         13         14          1
      7.625       .375
        103         35         42          1         13         14          1
      7.625       .375
        104         35         43          1         13         14          1
      7.625       .375
        105         37         41          1         13         14          1
      7.625       .375
        106         39         41          1         13         14          1
      7.625       .375
        107         41         45          1         13         14          1
      7.625       .375
        108         41         47          1         13         14          1
      7.625       .375
$ MEMBERS 109 THRU 128 MODEL THE SPG-60 PLATFORM ALONG WITH A FIXED MASS
        109         42         47          1         15         16          1
      7.625       .375
        110         43         45          1         15         16          1
      7.625       .375
        111         42         43          1         15         16          1
      7.625       .375
        112         45         47          1         15         16          1
      7.625       .375
        113         46         47          1         15         16          1
      7.625       .375
        114         45         46          1         15         16          1
      7.625       .375
        115         48         46          1         15         16          1
      7.625       .375
        116         52         53          1         15         16          1
      7.625       .375
        117         26         51          1         13         14          1
      7.625       .375
        118         27         51          1         13         14          1
      7.625       .375
        119         52         51          1         13         14          1
      7.625       .375
        120         53         51          1         13         14          1
      7.625       .375
        121         44         52          1         15         16          1
      7.625       .375
        122         53         59          1         15         16          1
      7.625       .375
        123         52         54          1         15         16          1
```

TABLE XXI

DATA FILE DD-963 FOREMAST continued

```
      5.75       .25
       159        63        71         1        29        30         1
      5.75       .25
$ SPS55 PLATFORM
       160        63        22         1        29        30         1
      5.75       .25
       161        63        23         1        29        30         1
      5.75       .25
       162        22        23         1        29        30         1
      5.75       .25
       163        64        23         1        29        30         1
      5.75       .25
       164        64        22         1        29        30         1
      5.75       .25
$ LOWER YARDARM AND BRACES
       165        44        62         1        15        16         1
     7.625      .375
       166        59        62         1        15        16         1
     7.625      .375
       167        49        44         1        31        32         1
     11.50       .50
       168        59        50         1        31        32         1
     11.50       .50
       169        49        55         1        31        32         1
     11.50       .50
       170        50        56         1        31        32         1
     11.50       .50
       171        14        49         1        33        34         1
      5.75       .25
       172        14        50         1        33        34         1
      5.75       .25
$********1*********2*********3*********4*********5*********6*********7***
$BLOCK I JOINT CONSTRAINT DATA          NCJ CARDS     FORMAT  7I10
$   JN        IX        IY        IZ        IXX       IYY       IZZ
$        |         |         |         |         |         |         |
         1         1         1         1         1         1         1
         2         1         1         1         1         1         1
         3         1         1         1         1         1         1
         4         1         1         1         1         1         1
         5         0         0         0         0         0         0
         6         0         0         0         0         0         0
         7         0         0         0         0         0         0
         8         0         0         0         0         0         0
         9         0         0         0         0         0         0
        10         0         0         0         0         0         0
        11         0         0         0         0         0         0
        12         0         0         0         0         0         0
        13         0         0         0         0         0         0
        14         0         0         0         0         0         0
        15         1         1         1         1         1         1
        16         0         0         0         0         0         0
        17         0         0         0         0         0         0
        18         0         0         0         0         0         0
        19         0         0         0         0         0         0
        20         0         0         0         0         0         0
        21         0         0         0         0         0         0
        22         0         0         0         0         0         0
        23         0         0         0         0         0         0
        24         0         0         0         0         0         0
        25         0         0         0         0         0         0
        26         0         0         0         0         0         0
        27         0         0         0         0         0         0
        28         0         0         0         0         0         0
        29         0         0         0         0         0         0
        30         0         0         0         0         0         0
        31         0         0         0         0         0         0
        32         0         0         0         0         0         0
        33         0         0         0         0         0         0
        34         0         0         0         0         0         0
        35         0         0         0         0         0         0
        36         0         0         0         0         0         0
        37         0         0         0         0         0         0
```

TABLE XXII

DATA FILE DD-963 FOREMAST continued

```
        38         0         0         0         0         0         0
        39         0         0         0         0         0         0
        40         0         0         0         0         0         0
        41         0         0         0         0         0         0
        42         0         0         0         0         0         0
        43         0         0         0         0         0         0
        44         0         0         0         0         0         0
        45         0         0         0         0         0         0
        46         0         0         0         0         0         0
        47         0         0         0         0         0         0
        48         0         0         0         0         0         0
        49         0         0         0         0         0         0
        50         0         0         0         0         0         0
        51         0         0         0         0         0         0
        52         0         0         0         0         0         0
        53         0         0         0         0         0         0
        54         0         0         0         0         0         0
        55         0         0         0         0         0         0
        56         0         0         0         0         0         0
        57         0         0         0         0         0         0
        58         0         0         0         0         0         0
        59         0         0         0         0         0         0
        60         1         1         1         1         1         1
        61         0         0         0         0         0         0
        62         0         0         0         0         0         0
        63         0         0         0         0         0         0
        64         0         0         0         0         0         0
        65         0         0         0         0         0         0
        66         0         0         0         0         0         0
        67         0         0         0         0         0         0
        68         0         0         0         0         0         0
        69         0         0         0         0         0         0
        70         0         0         0         0         0         0
        71         0         0         0         0         0         0
        72         0         0         0         0         0         0
        73         0         0         0         0         0         0
$********1*********2*********3*********4*********5*********6*********7***
$BLOCK J JOINT LOADING DATA             1 CARD    FORMAT I10
$     (OMIT IF NLC=0 IN BLOCK 8)
$  NLJ
$        |
        76
$                                    NLJ CARDS    FORMATI10,6F10
$   JN        FX        FY       FZ        TX        TY        TZ
$ HALYARD AND WIRE ANTENNA LOADS
$        |         |         |         |         |         |         |
        49      -50.    -100.0       0.0        0.        0.        0.
        50      -50.    -100.0       0.0        0.        0.        0.
        55      -50.    -100.0       0.0        0.        0.        0.
        56      -50.    -100.0       0.0        0.        0.        0.
        67        0.     -50.0       0.0        0.        0.        0.
$ SHIP'S MOTION LOADS
$   JN        FX        FY       FZ        TX        TY        TZ
$        |         |         |         |         |         |         |
         1       0.0       0.0     160.5       0.0       0.0       0.0
         2       0.0       0.0     163.3       0.0       0.0       0.0
         3       0.0       0.0      96.4       0.0       0.0       0.0
         4       0.0       0.0     137.5       0.0       0.0       0.0
         5       0.0       0.0     108.2       0.0       0.0       0.0
         6       0.0       0.0     184.3       0.0       0.0       0.0
         7       0.0       0.0      66.7       0.0       0.0       0.0
         8       0.0       0.0     184.3       0.0       0.0       0.0
         9       0.0       0.0     414.9       0.0       0.0       0.0
        10       0.0       0.0     467.0       0.0       0.0       0.0
        11       0.0       0.0     381.6       0.0       0.0       0.0
        12       0.0       0.0     381.6       0.0       0.0       0.0
        13       0.0       0.0      70.2       0.0       0.0       0.0
        14       0.0       0.0     325.4       0.0       0.0       0.0
        16       0.0       0.0     585.7       0.0       0.0       0.0
        17       0.0       0.0     528.5       0.0       0.0       0.0
        18       0.0       0.0     429.1       0.0       0.0       0.0
        19       0.0       0.0     226.9       0.0       0.0       0.0
```

TABLE XXIII

DATA FILE DD-963 FOREMAST continued

```
        20       0.0       0.0     214.8       0.0       0.0       0.0
        21       0.0       0.0     468.9       0.0       0.0       0.0
        22       0.0       0.0     539.0       0.0       0.0       0.0
        23       0.0       0.0     539.0       0.0       0.0       0.0
        24       0.0       0.0      91.6       0.0       0.0       0.0
        25       0.0       0.0     474.7       0.0       0.0       0.0
        26       0.0       0.0    3234.2       0.0       0.0       0.0
        27       0.0       0.0    2296.2       0.0       0.0       0.0
        28       0.0       0.0    1874.0       0.0       0.0       0.0
        29       0.0       0.0    1874.0       0.0       0.0       0.0
        30       0.0       0.0    1459.2       0.0       0.0       0.0
        31       0.0       0.0    1238.5       0.0       0.0       0.0
        32       0.0       0.0    1489.9       0.0       0.0       0.0
        33       0.0       0.0     211.7       0.0       0.0       0.0
        34       0.0       0.0     498.7       0.0       0.0       0.0
        35       0.0       0.0     606.8       0.0       0.0       0.0
        36       0.0       0.0     498.7       0.0       0.0       0.0
        37       0.0       0.0     725.9       0.0       0.0       0.0
        38       0.0       0.0     174.3       0.0       0.0       0.0
        39       0.0       0.0     725.9       0.0       0.0       0.0
        40       0.0       0.0     174.3       0.0       0.0       0.0
        41       0.0       0.0     345.5       0.0       0.0       0.0
        42       0.0       0.0    1729.0       0.0       0.0       0.0
        43       0.0       0.0    1729.0       0.0       0.0       0.0
        44       0.0       0.0    1425.6       0.0       0.0       0.0
        45       0.0       0.0    1810.4       0.0       0.0       0.0
        46       0.0       0.0    1468.1       0.0       0.0       0.0
        47       0.0       0.0    1810.4       0.0       0.0       0.0
        48       0.0       0.0    1468.1       0.0       0.0       0.0
        49       0.0       0.0     185.6       0.0       0.0       0.0
        50       0.0       0.0     185.6       0.0       0.0       0.0
        51       0.0       0.0     540.9       0.0       0.0       0.0
        52       0.0       0.0     965.8       0.0       0.0       0.0
        53       0.0       0.0     783.4       0.0       0.0       0.0
        54       0.0       0.0     464.2       0.0       0.0       0.0
        55       0.0       0.0     113.0       0.0       0.0       0.0
        56       0.0       0.0     113.0       0.0       0.0       0.0
        57       0.0       0.0     294.5       0.0       0.0       0.0
        58       0.0       0.0     436.2       0.0       0.0       0.0
        59       0.0       0.0    1425.6       0.0       0.0       0.0
        61       0.0       0.0     733.8       0.0       0.0       0.0
        62       0.0       0.0     304.6       0.0       0.0       0.0
        63       0.0       0.0     544.0       0.0       0.0       0.0
        64       0.0       0.0    1407.7       0.0       0.0       0.0
        65       0.0       0.0     135.0       0.0       0.0       0.0
        66       0.0       0.0     138.8       0.0       0.0       0.0
        67       0.0       0.0     100.3       0.0       0.0       0.0
        68       0.0       0.0      60.1       0.0       0.0       0.0
        69       0.0       0.0      60.1       0.0       0.0       0.0
        70       0.0       0.0     463.2       0.0       0.0       0.0
        71       0.0       0.0    1713.1       0.0       0.0       0.0
        72       0.0       0.0     237.0       0.0       0.0       0.0
        73       0.0       0.0    1081.2       0.0       0.0       0.0
$********1*********2*********3*********4*********5*********6*********7***
$BLOCK K FIXED MASS DATA          NFMASS CARDS   FORMAT I10,F10.0
$     (OMIT IF NFMASS=0 IN BLOCK B)
$   JN      MASS
$        |         |
$   PLATFORM BELOW SPQ-9
        18      32.0
        19      32.0
        20      32.0
        21      32.0
$   SPQ-9 AND PLATFORM
        26     890.0
        27     890.0
        28     890.0
        29     890.0
        30     890.0
        31     890.0
        32     890.0
$   SPG-60 AND PLATFORM
```

```
        42     940.0
        43     940.0
        44     940.0
        45     940.0
        46     940.0
        47     940.0
        48     940.0
        59     940.0
$   SPS-55 AND PLATFORM
        22     325.0
        23     325.0
        64     325.0
$   ANTENNAS AND OTHER FIXTURES
        49      25.0
        50      25.0
        55      12.0
        56      12.0
        64     220.0
        67      30.0
        68      26.0
        69      26.0
        70     120.0
        71     972.0
        73     565.0
$********1*********2*********3*********4*********5*********6*********7***
$BLOCK L DESIGN VARIABLE INFORMATION  CARDS AS REQ'D    FORMAT 8F10.0
$    (AREA AND DIMENSION VARIABLES     OMIT IF NDVAR1=0)
$    XA(I) .   .  .  XA(NDVAR1)
$        |         |         |         |         |         |         |
     13.75       .75     7.625      .375     8.625      .375     7.625      .375
     8.625      .375     12.50       .50     7.625      .375     7.625      .375
     7.625      .375     23.00      1.50      9.50       .50     14.00       .75
     10.00       .50     7.625      .375     7.625      .375     11.50       .50
      5.75       .25
$    XAL(I)
$        |         |         |         |         |         |         |
      8.00       .50     5.000      .250     5.000      .250     5.000      .250
     5.000      .250      8.00       .25     5.000      .250     5.000      .250
     5.000      .250     15.00       .50      6.00       .25     10.00       .50
      6.00       .25     5.000      .250      3.00       .10      8.00       .25
      3.00       .10
$    XAU(I)
$        |         |         |         |         |         |         |
     22.00      2.50     15.00      1.50     15.00      1.50     15.00      1.50
     15.00      1.50     22.00      2.50     15.00      1.50     15.00      1.50
     15.00      1.50     36.00      2.50     15.00      1.50     26.00      2.00
     15.00      1.50     15.00      1.50     12.00      1.50     22.00      1.50
     12.00      1.50
$********1*********2*********3*********4*********5*********6*********7***
$BLOCK N JOINT DISPLACEMENT CONSTRAINTS   NDSPLC CARDS  FORMAT 3I10,2F10
$    (OMIT IF NDSPLC=0 IN BLOCK B)
$   JN       CIR       LC         BL        BU
$        |         |         |         |         |
        67         1         1      -6.0       6.0
        67         3         1      -6.0       6.0
        46         3         1      -3.0       3.0
        48         3         1      -3.0       3.0
        22         1         1      -6.0       6.0
        22         3         1      -6.0       6.0
        23         1         1      -6.0       6.0
        23         3         1      -6.0       6.0
        64         5         1      -.02       .02
        31         2         1      -2.0       2.0
        31         5         1      -.02       .02
$********1*********2*********3*********4*********5*********6*********7***
$BLOCK O FREQUENCY CONSTRAINTS
$      2.0
$********1*********2*********3*********4*********5*********6*********7***
$BLOCK P END CARD
END
```

APPENDIX B

PROGRAM ORGANIZATION

A. DESCRIPTION

The program organization is layed out in the following flow charts. The main driver program (SADXM) calls a subdriver (SADXSD), and the optimizer of the user's choice. All changes required for replacement of the optimizer are made in SADXM, thus allowing for easy testing of several optimizers on the same problem.

SADXSD may be called from the main for input, analysis, and output. Printed output may vary as the user requires. A complete listing of all subroutines and their functions is given in Table XXIV.

TABLE XXIV

SUBROUTINE DIRECTORY

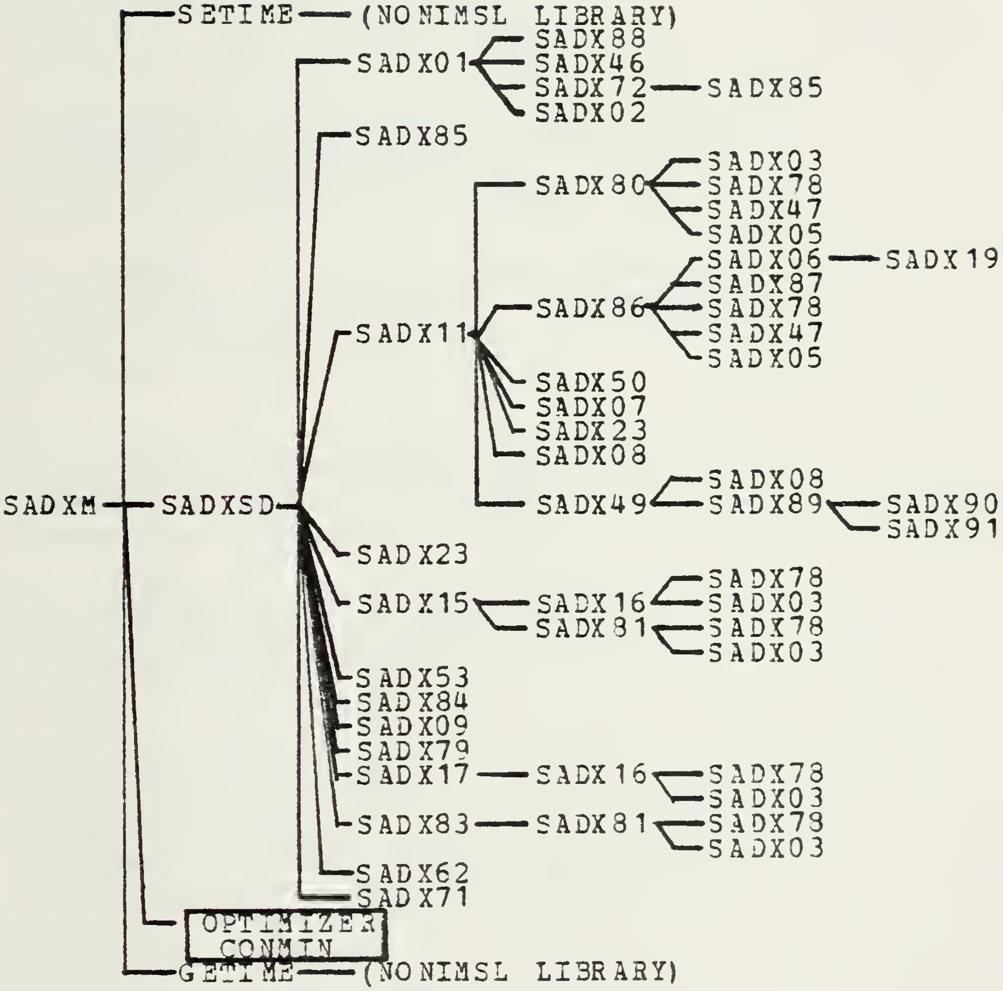
SADXM	DRIVER PROGRAM FOR USING THE ABOVE SUBROUTINES. SADXM MAY BE COUPLED TO OPTIMIZER OF USER'S CHOICE.
SADXSD	SUBDRIVER PROGRAM FOR COUPLING SADX ROUTINES TO SADXM
SADX01	THIS ROUTINE READS AND PRINTS INPUT DATA AND ORGANIZES PSEUDO-DYNAMIC STORAGE ALLOCATION
SADX02	BUILDS VECTORS JC AND IIK FOR FINITE ELEMENT STRUCTURAL ANALYSIS
SADX03	BUILDS THE 12x12 ELEMENT STIFFNESS MATRIX
SADX05	SUPERIMPOSES THE ELEMENT STIFFNESS MATRIX EK (OR ELEMENT MASS MATRIX EM) ON THE COMPACTED GLOBAL STIFFNESS MATRIX AK (OR THE GLOBAL COMPACTED MASS MATRIX AM)
SADX06	BUILDS GLOBAL LUMPED MASS MATRIX
SADX07	LU DECOMPOSES SYMMETRIC,POSITIVE-DEFINITE, SPARCE MATRICES,THE UPPER TRIANGLE OF WHICH IS STORED IN MATRIX AK (OR AM) WITH LEADING ZEROES NOT STORED
SADX08	FORWARD AND BACK SUBSTITUTES TO YIELD A SOLUTION A SET OF LINEAR EQUATIONS (DECOMPOSED BY SADX07 OR EQUIVALENT)
SADX09	PRINTS ALL JOINT DISPLACEMENTS FOR EACH LOAD CONDITION OF A FINITE ELEM. STRUCTURE
SADX11	ROUTINE TO ORGANIZE ANALYSIS
SADX15	CALCULATES VALUES FOR ALL DESIGN AND BEHAVIORIAL CONSTRAINTS AS DEFINED BY "SADX" PROGRAM
SADX16	CALCULATES STRESS IN TRUSS ELEMENT LNO UNDER LOAD CONDITION JJ
SADX17	PRINTS STRESSES AND/OR FORCES FOR TRUSS ELEMENTS
SADX19	ADDS ELEMENT MASS MATRIX AA OF ELEMENT LNO TO GLOBAL MASS MATRIX AM TO BUILD THE LUMPED MASS MATRIX
SADX23	CALCULATES WEIGHT OF TRUSS/FRAME STRUCTURE OR CALCULATE WEIGHT OF INDIVIDUAL MEMBERS
SADX36	CALCULATES (XEIG-T*AM*XEIG) FOR GRADIENT CALCULATIONS IN FREQUENCY CONSTRAINTS
SADX37	CALCULATES EIGENVALUE GRADIENT INFORMATION IN FINITE ELEMENT STRUCTURAL ANALYSIS AND DESIGN

SADX46	READS INPUT INFORMATION FOR TRUSS ELEMENTS
SADX47	TRANSFORMS THE ELEMENT STIFFNESS MATRIX EK (OR ELEMENT MASS MATRIX EM) FROM LOCAL TO GLOBAL COORDINATES
SADX49	SOLVES REAL EIGENVALUE PROBLEMS USING THE SUBSPACE ITERATION METHOD
SADX50	BUILDS INITIAL SET OF BASIS VECTORS FOR EIGENSOLUTION BY REDUCED BASIS METHOD
SADX53	PRINTS MEMBER INFORMATION FOR TRUSS ELEMENTS
SADX62	PRINTS NEIG EIGENVALUES STORED IN EIGVAL, AND THEIR CORRESPONDING EIGENVECTORS STORED IN XEIG
SADX71	PRINTS G VECTOR OF CONSTRAINTS
SADX72	READS IN FRAME ELEMENT INPUT DATA
SADX78	BUILDS 3x3 TRANSFORMATION ARRAY TRFORM FOR TRANSFORMING FROM LOCAL TO GLOBAL COORDINATES
SADX80	CALLS SADX03 TO BUILD THE ELEMENT STIFFNESS MATRIX; CALLS SADX47 TO TRANSFORM THE MATRIX; AND CALLS SADX05 TO BUILD THE REDUCED GLOBAL STIFFNESS MATRIX
SADX81	CALCULATES STRESS IN FRAME ELEMENT LNO UNDER LOAD CONDITION JJ (IF JJ=0 STRESSES CALCULATED FOR ALL LOAD CONDITIONS)
SADX82	READS INPUT DATA FOR FRAME ELEMENTS WITH SPECIFIED SECTION TYPES
SADX83	PRINTS STRESSES AND/OR FORCES FOR FRAME ELEMENTS
SADX84	PRINTS MEMBER INFORMATION FOR FRAME ELEMENTS
SADX85	CALCULATES SECTION PROPERTIES FOR FRAME ELEMENTS OF A SECTION TYPE GIVEN BY LSECT
SADX86	CALLS EITHER SADX06 TO BUILD THE LUMPED MASS MATRIX OR BUILDS THE CONSISTENT MASS MATRIX BY CALLING SADX87 TO BUILD THE ELEMENT MASS MATRIX, SADX78 TO BUILD THE TRANSFORMATION MATRIX, SADX47 TO TRANSFORM THE ELEMENT MASS MATRIX, AND SADX88 TO ASSEMBLE THE COMPACTED GLOBAL MASS MATRIX
SADX87	CALLS BUILDS THE ELEMENT CONSISTENT MASS MATRIX

SADX88	CONVERTS UNFORMATTED DATA TO FORMATTED DATA IN FIELDS OF 10, EACH RIGHT JUSTIFIED AND ACCEPTS $COMMENT CARDS IN DATA
SADX89	SOLVES EIGENVALUE PROBLEM |A-ALAMBD*B| X=0
SADX90	SOLVES EIGENVALUE PROBLEM
SADX91	SOLVES EIGENVALUE PROBLEM
SETIME	STARTS EXECUTION TIMER (NONIMSL LIBRARY)
GETIME	STOPS EXECUTION TIMER (NONIMSL LIBRARY)

TABLE XXV

PROGRAM BLOCK DIAGRAM



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